U.S. Renewable Electricity Generation: Resources and Challenges

August 5, 2011

Congressional Research Service
https://crsreports.congress.gov
R41954

CRS REPORT
Prepared for Members and
Committees of Congress

Summary

The United States faces important decisions about future energy supply and use. A key question is how renewable energy resources might be used to meet U.S. energy needs in general, and to meet U.S. electricity needs specifically. Renewable energy sources are typically used for three general types of applications: electricity generation, biofuels/bioproducts, and heating/cooling. Each application uses different technologies to convert renewable energy sources into usable products. The literature on renewable energy resources, conversion technologies for different applications, and economics is massive. This report focuses on electricity generation from renewable energy sources. In 2010, renewable sources of energy were used to produce almost 11% (7% from hydropower and 4% from other renewables) of the 4 million gigawatthours of electricity generated in the United States.

This report provides a summary of U.S. electricity generation potential from wind, solar, geothermal, hydroelectric, ocean-hydrokinetic, and biomass sources of renewable energy. The focus of this report is twofold: (1) provide an assessment of U.S. renewable electricity generation potential and how renewables might satisfy electric power sector demand, and (2) discuss challenges, issues, and barriers that might limit renewable electricity generation deployment.

Data sources from 15 different organizations were reviewed to derive estimates of electricity generation potential. One key finding is that there exists no uniform national assessment of renewable electricity generation potential. No standard methods or set of assumptions are used to estimate renewable electricity generation potential. So even existing assessments for individual energy sources are difficult to compare objectively. In order to compare various estimates on an equivalent basis, CRS engaged experts in each renewable energy resource area to help normalize electricity generation potential estimates into a common metric: gigawatthours per year.

After surveying, researching, and normalizing all of the third-party electricity generation estimates, results indicate that renewable energy sources may, in principle, have the potential to satisfy a large portion of U.S. electricity demand. However, a number of potential barriers to large-scale deployment exist, including cost, power system integration, intermittency and variability, land requirements, transmission access, possible limits to the availability of key materials and resources, certain environmental impacts, specialized infrastructure requirements, and policy issues. Ultimately, the amount of renewable electricity generation in the U.S. may be dependent on the ability to address these deployment barriers. The Energy Information Administration projects that U.S. renewable electricity generation will increase from 11% today to between 14% and 15% in 2035.

As Congress considers policy options associated with increasing renewable electricity generation, policy makers may assess potential benefits such as emissions reduction, job creation, and global competitiveness, along with possible risks and consequences such as electricity cost and price increases, electricity delivery reliability, and environmental impacts associated with large-scale deployment of renewable electricity generation technologies.

Contents

Figures

Tables

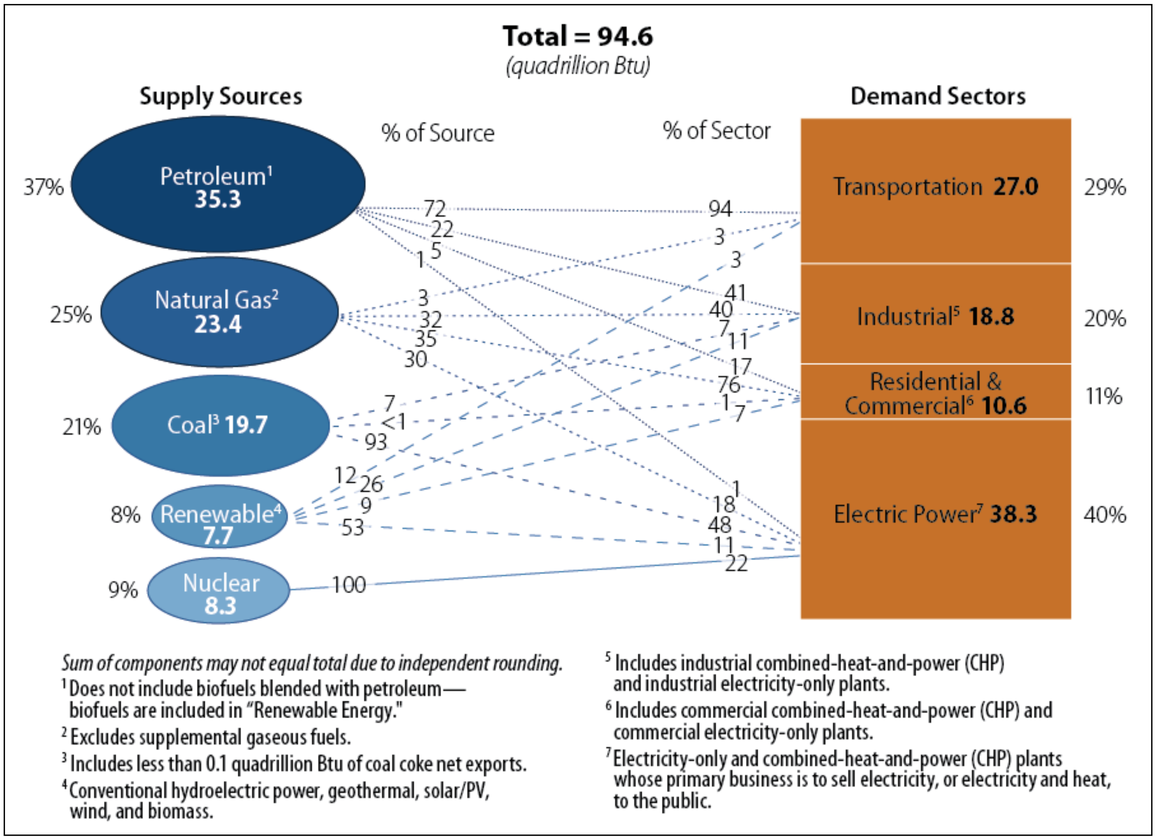
Contacts

Introduction

The U.S. energy sector is large and complex. Multiple energy sources, including fossil, nuclear, and several renewable sources, are used to produce energy products for multiple demand sectors (transportation, electricity, industrial, and residential/commercial). Today, fossil fuels are the dominant sources of energy, comprising 83% of total U.S. primary energy supply. Renewable energy sources, which can be used to generate electricity, produce liquid transportation fuels, and provide heating and cooling for industrial and residential/commercial sectors, provided 8% of total U.S. primary energy supply in 2009 (see **Figure 1**).

Figure 1. U.S. Primary Energy Flow by Supply Source and Demand Sector, 2009

(Values are in Quadrillion Btu and Percentage of Total)



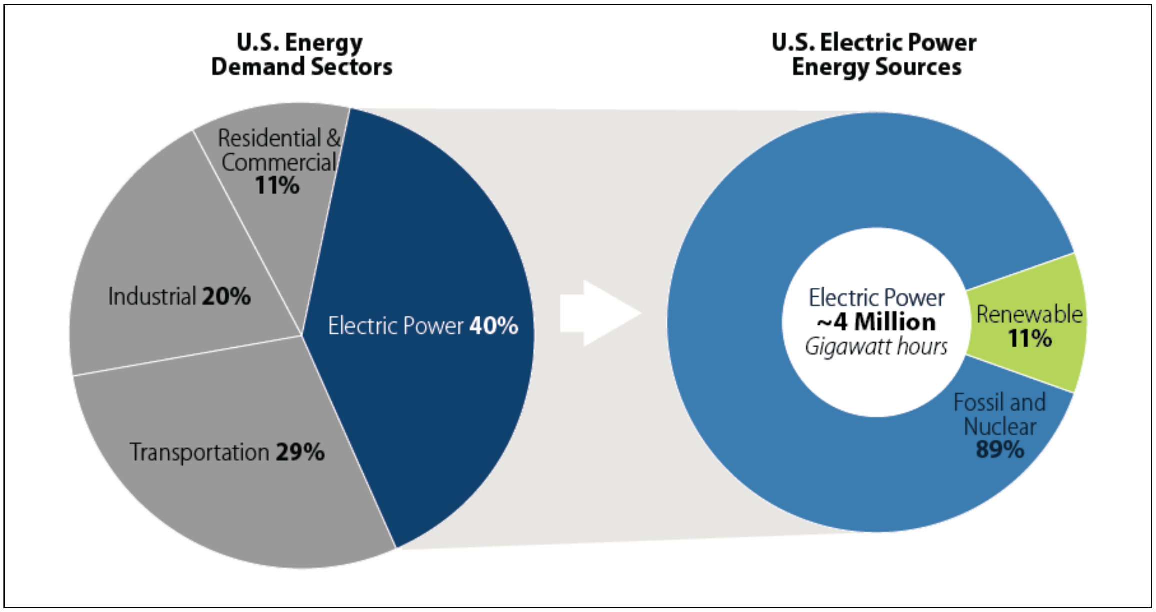
Source: CRS adaptation of Energy Information Administration, Annual Energy Review 2009, http://www.eia.doe.gov/totalenergy/data/annual/pdf/pecss_diagram_2009.pdf

The largest source of energy demand in the United States is the electric power sector, which consumed just over 40% of total U.S. energy supply in 2009. The U.S. electric power sector generates approximately 4 million gigawatthours of electricity each year. Like the total U.S. energy sector, electricity generation is dominated (89%) by fossil fuels and nuclear power. Renewable electricity generation, including hydro, wind, solar, geothermal, and biomass, contributed 11% of total U.S. electric power in 2009 (**Figure 2**).[1] Most U.S. renewable generation

[1] Energy Information Administration, Annual Energy Review 2009, http://www.eia.doe.gov/totalenergy/data/annual/pdf/pecss_diagram_2009.pdf.

comes from conventional hydropower, which has limited growth potential. Other renewable electricity sources constitute about 4% of U.S. generation, but have been growing more rapidly.

Figure 2. Supply Sources for U.S. Electric Power Sector



Source: Energy Information Administration, Annual Energy Review 2009, http://www.eia.doe.gov/totalenergy/data/annual/pdf/pecss_diagram_2009.pdf.

The purpose of this report is to analyze the prospects, opportunities, and challenges for renewable energy sources to increase their contribution to the electric power sector.

There is growing interest in increasing the amount of renewable electricity generation to reduce the amount of fossil fuel consumption for U.S. electric power. That interest is driven by concerns about greenhouse gas emissions, the realization that economically recoverable fossil fuel supplies are ultimately finite, and the desire to position the United States as a global leader for renewable energy technology and manufacturing.[2] These concerns are counter-balanced by the fact that fossil fuel electricity generation has long been—and generally continues to be—the least expensive form of electricity generation, by the fact that the United States has access to considerable resources of coal and natural gas for electricity generation, and from the economic and cultural inertia of the existing infrastructure in place for coal and natural gas to be used in large quantities for electricity generation. Renewable electricity generation provides two advantages when compared to fossil generation: (1) it relies on energy sources that may not decline over time, and (2) it produces little or no net greenhouse gas emissions or other pollutants

[2] Decreasing U.S. reliance on foreign oil is not included here because the focus of this report is on electricity generation. Petroleum contributed 1% of electricity generation in 2009. Based on current U.S. energy infrastructure, adding additional renewable electricity generation capacity will have a negligible, if any, impact on U.S. oil import dependency. However, electrification of the transportation fleet could potentially result in decreasing total U.S. oil demand. Renewable electricity generation combined with electric vehicle market penetration could potentially result in lower oil import requirements.

during use.[3] However, renewable electricity generation does have liabilities and implementation challenges that will be further discussed in this report.

This report addresses two fundamental questions about U.S. renewable electricity generation potential: (1) How much renewable electricity generation might be possible in the United States?[4] and (2) What technical, operational, and economic challenges might renewables encounter when considering large-scale deployment for electricity generation?

Renewable Electricity Concepts and Units

Definition and Characteristics of Renewable Electricity

Renewable electricity is derived from renewable energy sources that "regenerate and can be sustained indefinitely."[5] This report does not use the term "clean energy" or "alternative energy," which are terms used by some to include renewable energy resources *plus* other sources that may emit little or no carbon dioxide during use, such as nuclear plants and coal-fired power plants equipped with carbon capture and sequestration capabilities. A discussion of biomass used to generate electricity is included, but biofuels are mentioned only briefly. This study is focused on wind, solar, hydroelectric, geothermal, biomass, and ocean/hydrokinetic energy sources used to generate electricity.

"Renewable energy" sources for electricity generation are often discussed as if they were a single entity, but renewable energy sources are more numerous and variable than fossil energy sources. Fossil fuels comprise oil, natural gas, and coal. The three major types of fossil fuels are extracted from the earth's crust by drilling or mining. Each of these fuels has very high energy density and is used primarily through combustion to exploit the heat produced. Renewable energy sources are more numerous and diverse and, thus, harnessing renewable energy requires a number of different technologies. Some of the distinctive characteristics of renewable energy are:

- *Renewable energy sources for electricity generation are numerous.* Sun, wind, flowing water in streams, flowing water in tidal channels, wave action in oceans, the earth's natural heat, biological materials, and others comprise the current portfolio of renewable energy sources, and additional renewable sources may be identified in the future.
- *Each renewable energy source may be exploited in multiple ways to generate electricity using different technologies and materials.* For example, the energy of the sun may be used by concentrating the energy to generate steam that drives electric turbines (concentrating solar power), or the energy of the sun may be converted directly to electricity using semiconducting materials (photovoltaics). Furthermore, photovoltaic electricity may be produced using solar panels that consist of crystalline silicon, cadmium telluride, or other materials, and each material has unique characteristics.

[3] Biomass and biofuels release CO_2 during combustion, but are considered by some to have zero net emissions because the CO_2 released was taken up from the atmosphere to grow the plants. However, there is debate about biomass being considered carbon neutral. For more information see CRS Report R41603, *Is Biopower Carbon Neutral?*, by Kelsi Bracmort.

[4] CRS is aware that the National Renewable Energy Laboratory (NREL) is in the process of publishing an analysis about U.S. renewable electricity generation potential. However, the NREL work was not available to influence the research for this report.

[5] Energy Information Administration, http://www.eia.gov/energyexplained/index.cfm?page=renewable_home.

- *Renewable energy sources for electricity generation are naturally dispersed with relatively low energy densities.* Fossil energy sources are typically concentrated as liquids or solids by millions of years of natural heating and pressure processes, which result in relatively high energy density that is accessible in wells or mines. In contrast, renewable energy sources are typically diffuse and require multiple technologies and management systems to gather and concentrate the resources.
- *Each renewable electricity generation project/installation can vary in size.* Renewable electricity generation systems are being installed in large, megawatt-scale projects that feed electricity into the electric grid for consumption along with electricity from other sources. In fact, the largest electric power plant in the United States is a hydroelectric facility, Grand Coulee Dam, which has a capacity of 7.08 GW.[6] At the same time, individual homes are being powered by small, kilowatt-scale rooftop solar panels. Also, wind turbines may be large, up to 5 megawatt (MW) utility-scale turbines, or small, approximately 5 kilowatt (kW) residential scale units.

Renewable Electricity Terminology and Units

This section defines terms and units used to describe and quantify renewable energy sources, and electricity generation potential from these sources, and how renewable energy might be compared to other forms of energy. Although this report focuses on renewable energy, discussions of fossil fuel units and consumption are included to facilitate comparisons with renewable forms of energy.

Measuring Energy: Fossil versus Renewable

Fossil fuels have traditionally been measured and marketed in the units of the physical material—barrels (42 gallons) of oil, short tons (2,000 pounds) of coal, or cubic feet of natural gas—transported to the point of end use. The use of volume or weight for measuring fossil fuels makes it challenging to compare the energy content among fossil fuels, and also contributes to the difficulty in clearly communicating the amounts of renewable energy that will be needed to replace fossil fuels. Each fossil fuel unit of measure has a corresponding energy content, which is typically expressed in terms of British Thermal Units (Btu).[7]

With the exception of biomass (typically measured in tons), each renewable energy source has its own unit of measure that may not be expressed as volume or weight. For example, wind energy is typically expressed in terms of *wind speed* (reported as meters per second); solar energy is typically expressed in terms of daily *insolation* (reported as kilowatthours per meter-square per day); hydroelectric is derived from flowing water, typically expressed in terms of water *flow rate* and *velocity*. In order to estimate annual electricity generation potential from renewable energy sources, experts must make assumptions about conversion equipment efficiencies and annual hours of operation.

[6] Energy Information Administration, http://www.eia.gov/state/state-energy-profiles-analysis.cfm?sid=WA.

[7] A British thermal unit (Btu) is a measure of the energy (heat) content of fuels. It is the quantity of energy (heat) required to raise the temperature of 1 pound of liquid water by 1°F at the temperature that water has its greatest density (approximately 39°F), http://www.eia.doe.gov/energyexplained/index.cfm?page=about_btu.

Expressing Renewable Electricity Generation Potential: Watthour

Renewable electricity generation potential is typically expressed in terms of watthours (see text box below). A watthour (Wh) is a unit of electrical energy that can be generated, distributed, and consumed. A watthour can also be purchased and/or sold. For example, a residential electricity bill is typically calculated by multiplying the number of kilowatthours (kWh) consumed by a residence times the rate per kilowatthour charged by the electric power provider.[8] In 2009, U.S. total electricity net generation was approximately 4 million gigawatthours.[9] For the purpose of this report, renewable electricity generation potential, for all renewable energy sources, is expressed in terms of annual gigawatthours (GWh).

Power versus energy: What's the difference between a watt and a watthour?

Some energy reports provide statistics in units of power while other reports use units of energy. Power and energy are related, but they are not the same thing. Energy equals power multiplied by the amount of time the power is applied. Conversely, power is the rate at which energy is produced or consumed. Power is measured in watts, energy is measured in watthours. An electrical generator with 50 megawatts of power (or nameplate capacity) would generate 50 megawatthours of electrical energy for each hour it operates. The power capacity of a generator conveys only the size of the device, thus, when it's not operating, a generator does not produce any energy even though the power capacity remains the same. Power capacity is a critical variable when selecting a device to do a specific job, but the energy produced by the device depends on the amount of time it operates. The report examines total energy production with little regard to the size of the devices that produce it.

Authoritative Data Sources for Renewable Energy Resources

Various renewable electricity resource estimates for the United States are calculated by different institutions that use different processes, methodologies, and assumptions. No uniform methodologies exist for estimating and comparing the resource potential of different forms of renewable energy that might be used to generate electricity (see text box below).

Traditional fossil fuel energy resource assessments are conducted through detailed geologic studies and the application of rigorously vetted methodologies. In contrast, most renewable electricity generation resource estimates are subject to the unique methods and assumptions of the organization conducting the assessment. Fossil energy resource estimates typically classify resources into categories such as: resource base, technically recoverable, economically recoverable, and reserves.[10] In principle, renewable energy resources should be measurable using similar analysis of the natural processes (wind, solar insolation, water flow, geothermal heat, etc.), adjusted for the effectiveness of the respective energy extraction technologies, and then couched in economic terms based on economic conditions and parameters.

In reality, it is very difficult, time consuming, and expensive to collect high quality data for wind, solar, stream flow, geothermal and biomass energy at a fine scale over the entire nation on an hourly, daily, or seasonal basis, as appropriate. In addition, the basic physics are different for extracting energy from solar, wind, hydro, geothermal, and biomass sources. Those physical differences give rise to different technologies, and many renewable energy technologies exhibit dramatically different performance according to geographic location and time of day or time of year. Therefore, estimating the amount of each type of renewable energy that is available to the nation is a challenging task. Examination of the literature reveals that estimates of available

[8] A kilowatthour is equal to one thousand watthours. 1 kWh = 3,412 Btu.

[9] A gigawatthour is equal to one billion watthours.

[10] For more information on U.S. fossil fuel resources, see CRS Report R40872, *U.S. Fossil Fuel Resources: Terminology, Reporting, and Summary*, by Gene Whitney, Carl E. Behrens, and Carol Glover.

renewable energy resources vary widely. Attempting to compare estimates for different types of renewable energy multiplies those challenges.

The most reliable data for the various renewable energy sources come from national data collection programs from federal agencies. For example, the National Renewable Energy Laboratory, funded by the Department of Energy and its partners, operates programs designed to collect such data and has worked to identify the areas within the United States that are optimally suited for exploitation of various renewable energy sources. Other federal and state agencies, federal labs, and academic institutions also collect, analyze, and report renewable energy resource data. These data and estimates change over time as data collection technologies advance and understanding of the natural processes improves. Nevertheless, comparing renewable energy assessments from different sources is difficult, and a complete and comprehensive assessment of all available renewable energy resources for the nation does not yet exist. Collection of high quality data on renewable energy sources at a fine scale over broad ranges of time and geography will likely be an ongoing need for the nation. **Table 1** summarizes sources of information reviewed for this report.

Table 1. U.S. Renewable Electricity Generation Potential—Information Sources

Renewable Electricity Resource	Sources of Data Reviewed
Wind	National Renewable Energy Laboratory (NREL); American Wind Energy Association (AWEA); Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE).
Solar	NREL; Solar Energy Industries Association (SEIA); DOE EERE.
Hydro	DOE EERE, Oak Ridge National Laboratory (ORNL); Idaho National Laboratory (INL); National Hydropower Association (NHA).
Geothermal	United States Geological Survey (USGS); NREL; Massachusetts Institute of Technology (MIT); Geothermal Energy Association (GEA).
Ocean-Hydrokinetic	Electric Power Research Institute (EPRI); DOE EERE; New York University; Ocean Renewable Energy Coalition (OREC).
Biomass	DOE EERE; United States Department of Agriculture (USDA); NREL, Biomass Power Association (BPA).

Source: CRS.

How Much Renewable Energy Is Available? It Depends … And It Can Change

The overriding goal of this report is to provide Congress with accurate, comparable, and current U.S. renewable electricity resource estimates using currently available data. Answering the question "How much renewable electricity is possible in the United States?" is the primary objective. However, the answer to this key question is "it depends, and it will very likely change over time."

No centralized authoritative body or organization currently exists to develop and enforce standards for renewable electricity resource assessment methodologies and assumptions used to calculate estimates. Renewable electricity resource estimates come from multiple organizations. As a result, renewable electricity generation potential estimates are derived using different methodologies and different assumptions which, in turn, produce different estimates.

Estimates for renewable electricity generation potential in the United States depend on several factors such as the methodology used to calculate the estimates and certain assumptions that can have a major impact on the calculation results. With regard to methodologies used, resource estimates surveyed for this report came from several different organizations that include federal labs, industry organizations, and academic institutions. Each organization typically uses a unique methodology to calculate resource estimates. Therefore, comparing all of these estimates on an "apples-to-apples" equivalent basis is a challenge.

Key assumptions made for calculating renewable electricity generation potential can also have a major impact on resulting estimates. Geothermal electricity is a good example of how assumptions can impact renewable electricity generation estimates. Both USGS and MIT have published reports that estimate the amount of electricity generation potential from U.S. geothermal resources.[11] However, MIT estimates are more than 10 times larger than those from USGS. Two key assumptions explain most of this discrepancy: (1) Resource depth: The USGS geothermal study only considered geothermal potential at depths of 6 kilometers below the earth's surface whereas the MIT report considered depths of 10 kilometers, and (2) Which U.S. states were included: The USGS study only included 14 western states, Alaska, and Hawaii, while the MIT study included all 50 states. Thus, understanding assumptions for understanding and comparing the various resource potential estimates is critical.

Understanding certain exclusions for the various resource potential estimates is also important. Many of the studies surveyed for this report excluded certain areas from development based on several factors (national parks, urban areas, etc.). However, the types of exclusions and the constraints that result from exclusions vary. Comparing wind estimates and hydroelectricity estimates is one example. Wind electricity generation potential estimates exclude certain land areas. After these exclusions are taken into account, the NREL study referenced for this report assumes that wind projects can be built anywhere as long as the wind resource is large enough to meet certain electricity production levels. Hydroelectricity generation estimates, on the other hand, also include certain land area exclusions but apply additional filters such as the location being within one mile of a road and a transmission line. If identical exclusions were applied to all renewable electricity generation resource assessments, resource potential results may be quite different.

Further, estimates for renewable electricity generation potential in the U.S. will likely change over time as resource estimate methodologies improve, renewable electricity generation technologies are developed and commercialized, and better information about the magnitude and quality of renewable energy resources is made available. As a result, estimates of renewable electricity generation potential could either go up or down in the future.[12]

U.S. Renewable Electricity Use and Potential

This section provides a brief overview of current U.S. renewable electricity generation, followed by a series of discussions of specific renewable electricity technologies. Current electricity

[11] "Assessment of Moderate- and High-Temperature Geothermal Resources of the United States," U.S. Geological Survey, 2008, available at http://pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf, and "The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century," Massachusetts Institute of Technology, 2006, available at http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf.

[12] Resource estimate changes are not unique to renewable energy. Fossil fuel estimates typically change in response to technology, economic conditions, improved data sets, etc. Shale gas in the United States is an example of how resource estimates can change over time.

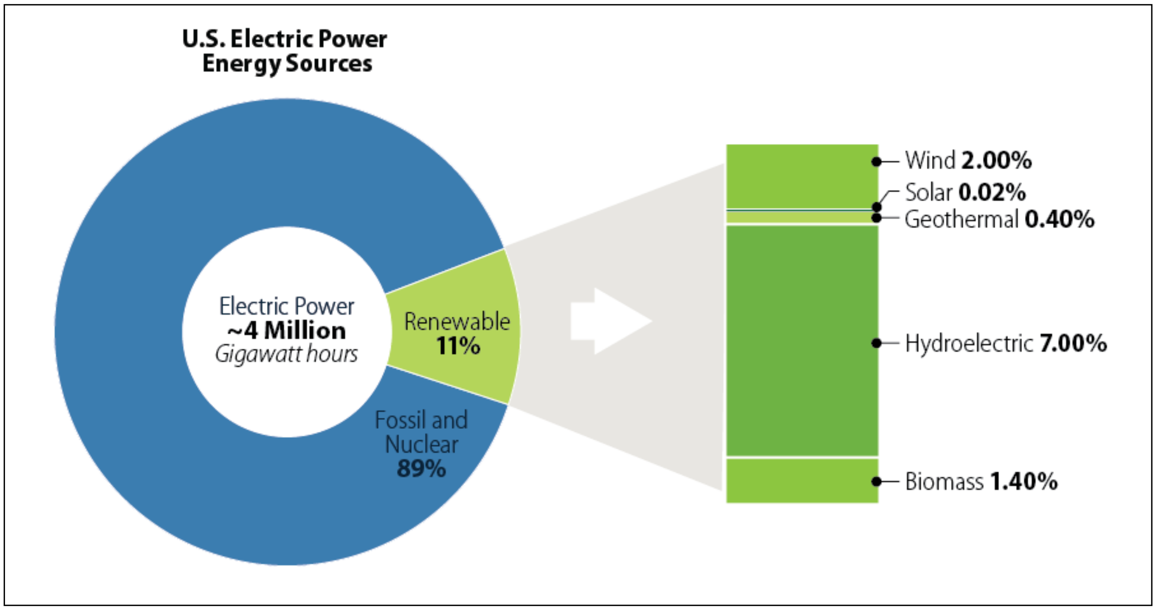
generation, estimated potential generation, and deployment challenges are discussed for wind, solar, geothermal, hydroelectric (hydro), ocean-hydrokinetic, and biomass energy sources.

Summary of Current U.S. Renewable Electricity

In 2009 renewable energy resources provided 11% of U.S. electricity net generation. Renewable electricity was derived from wind, solar, geothermal, hydro, and biomass energy sources. The largest source of renewable electricity was hydro. Wind and biomass each contributed between 1% and 2% of total U.S. electricity net generation. Solar and geothermal electricity generation contributed relatively small amounts to the renewable electricity portfolio mix (**Figure 3**).

Figure 3. U.S. Electricity Generation from Various Renewable Sources, 2009

(Percentage of each renewable source)



Source: Energy Information Administration, Annual Energy Review 2009, http://www.eia.doe.gov/totalenergy/data/annual/pdf/pecss_diagram_2009.pdf.

Notes: Renewable electric power percentages may not add to 11% because of independent rounding error.

Future Renewable Electricity Generation Potential

The following sections discuss the estimated range of electricity generation potential from wind, solar, geothermal, hydro, ocean-hydrokinetic, and biomass renewable energy sources. A discussion of technology and cost considerations is presented for each respective renewable source of electricity. As discussed above, comparing renewable electricity generation resource estimates is a challenging task. The approach used to derive the resource estimate range for each technology is described in the footnotes to each renewable energy source section. **Table 2** provides a summary of U.S. renewable electricity generation potential, based on the research and analysis performed for this report, current and projected renewable electricity generation potential, cost of electricity estimates, and a summary of key challenges for each renewable energy source. As the table shows, renewable electricity generation potential is compared to 2009 total U.S. net generation of approximately 4 million gigawatthours (GWh). This approach was used in order to indicate the maximum electricity generation contribution that might be available from each renewable energy source. Furthermore, the reader is advised that levelized cost of energy (LCOE) estimates presented in **Table 2** only reflect electricity costs associated with capacity additions in EIA's Annual Energy Outlook 2011. For more information, see the "Levelized Cost of Energy (LCOE)" section below.

Research and analysis conducted for this report indicates that renewable energy sources may, theoretically, have the potential to satisfy a large portion of U.S. electric power needs. However, numerous technical, operational, economic, and practical challenges will likely be encountered, which may ultimately limit the potential contribution of renewable electricity generation. These challenges are discussed in a following section. Furthermore, while the potential for renewable electricity generation in the country is vast, EIA Annual Energy Outlook 2011 reference case projections indicate that renewables will contribute between 14% and 15% of total U.S. electricity generation by 2035.[13] Also, the quality of resources estimates is different for each renewable technology, and these estimates may change as new data are collected and new assessments are conducted. The current estimates represent a snapshot in time and must be continually updated as additional data become available.

[13] For more information about the Annual Energy Outlook reference case see, Energy Information Administration, "Annual Energy Outlook 2011," Report Number: DOE/EIA-0383(2011), April 2011, available at http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf.

Table 2. Summary of U.S. Renewable Electricity Resources and Challenges

Electricity Generation Potential	Wind[a]		Solar[b]		Geothermal		Hydro		Ocean-Hydrokinetic		Biomass[c]	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Electricity Potential (GWh/yr) ** Total estimated resource potential*	32,500,000	61,400,000	4,000,000	56,300,000	927,791	36,991,864	558,145	613,333	287,850	2,161,350	125,730	1,428,780
% of 2009 total U.S. generation	>100%	>100%	100%	>100%	23%	>100%	14%	16%	7%	55%	3%	36%
Current and Forecasted Generation												
2009 Generation (GWh)	73,886		891		15,009		273,445		not available		54,493	
% of 2009 total U.S. generation	1.87%		0.02%		0.38%		6.92%		not available		1.38%	
EIA LCOE[d] $/MWh *** Only for capacity additions forecasted in AEO 2011*	$82 to $349		$159 to $642		$92 to $116		$59 to $121		not available		$99 to $134	
2035 Generation (GWh) **** EIA AEO 2011 forecast (reference case)*	160,880		3,970		49,190		310,590		not available		47,440	
% of 2035 total est. generation	3.48%		0.09%		1.06%		6.70%		not available		1.02%	
Deployment Challenges, Issues, and Barriers?												
Power System Integration	Yes		Yes		No		No		Yes		No	
Transmission	Yes		Yes		Yes		Yes		Yes		Yes	
Cost	No/Yes		Yes		Yes		No/Yes		Yes		Yes	
	- Onshore wind costs are in the range of fossil electricity costs - Offshore costs are higher		- Currently the highest cost source of renewable electricity		- Enhanced geothermal system (EGS) costs are estimates only; NREL indicates EGS LCOE could be as high as $1,000/MWh		- One of the oldest and lowest-cost sources of renewable electricity - Emerging small/low-head hydro costs unknown		- Actual cost of ocean and hydrokinetic electricity is unknown		- Cost of electricity can be impacted by logistics and feedstock quality	
Intermittency/Variability	Yes		Yes		No		Yes		Yes/No		No	
	- Wind resources can vary on an hourly, daily, and/or annual basis		- Cloud coverage and other weather events can degrade solar technology performance; solar energy not available at night		- Geothermal electricity production can be predictable and may operate at high capacity factors		- Hydropower resource can vary based on annual rain/snow fall		- Wave energy resources can vary based on the amount of wind; tidal energy may be predictable		- Biomass electricity plants can operate at high capacity factors and may provide baseload power	
Technology	No/Yes		Yes		Yes		Yes		Yes		No/Yes	
	- Onshore wind technology considered commercial - Offshore wind may require further technology development		- Emerging PV technologies that may improve efficiencies & reduce costs - Some CSP technologies may require further engineering, development,		- EGS, the largest potential source of geothermal electricity, technology is not yet commercially available - Specialized drilling		- Small and low-head/low-power technologies are being developed and matured but some are not yet commercially available		- Ocean and hydrokinetic energy technologies are considered "emerging" with no commercially available electricity		- Biomass combustion technology might be considered commercial - Some technical issues (tar production, equipment fouling,	

Electricity Generation Potential	Wind[a]	Solar[b]	Geothermal	Hydro	Ocean-Hydrokinetic	Biomass[c]
	Low High	Low High	Low High	Low High	Low High	Low High
	to operate in harsh ocean environment	and demonstration before being commercial	equipment may be required		generation technologies	etc.) may have to be addressed
Environmental Impact	Yes	Yes	Yes	Yes	Yes	Yes
	- Land use, habitat and scenic disturbance, noise, and bird mortality are potential environmental issues associated with wind projects	- Water use requirements for some solar thermal technologies - Land use and associated habitat disturbance - Mobilization of trace metals	- Water use; discharge of metals and toxic gas - Ground/surface water pollution - Land subsidence and seismicity	- Ecosystem changes; fish migration and mortality - Habitat damage; water quality degradation	- Alteration of currents and waves; alteration of sediment disposition; habitat impacts; noise; electromagnetic fields; toxicity of lubricants and other fluids; animal injury from moving parts; degradation of water quality	- Biomass combustion for electricity generation emits NOx, CO2, and other emissions - Land use/change associated with biomass production - Carbon neutrality of biomass combustion is a possible issue
Infrastructure	Yes	Unknown	Unknown	Unknown	Yes	Yes
	- Offshore wind may require specialized vessels, portside infrastructure, under-sea transmission, etc.	Information regarding potential infrastructure issues not available	Information regarding potential infrastructure issues not available	Information regarding potential infrastructure issues not available	- Specialized infrastructure may be needed to install and maintain operational projects	- Logistics infrastructure may be needed to gather and process biomass material
Materials and Resources	Yes	Yes	Unknown	Unknown	Yes	Yes
	- High volumes of steel, concrete, and rare-earth metals may be needed to support large scale wind deployment	- High volumes of steel and concrete may be needed to support large-scale deployment of utility-scale solar; silicon, tellurium, cadmium, silver, and other commodities may be required for large-scale PV deployment	Information regarding potential materials and resources issues not available	Information regarding potential materials and resources issues not available	- Materials that can operate for long periods of time in a corrosive ocean environment may need to be developed	- Economical electricity generation from biomass may require adequate biomass resources within a defined geographic area

Source: CRS; Various sources as identified and referenced in the respective sections of this report.

a. Includes both onshore and offshore wind.

b. Includes both photovoltaic and concentrating solar.

c. Does not include liquid biofuels used for transportation.

d. LCOE = Levelized Cost of Energy.

Wind

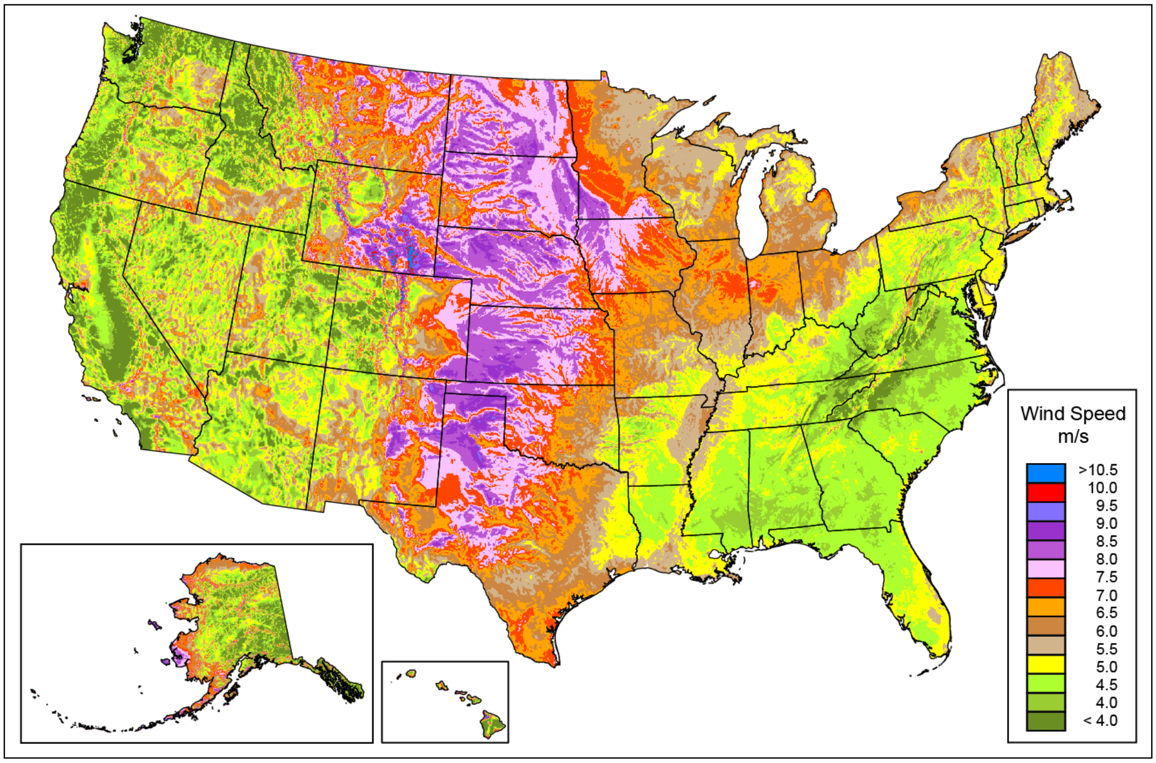
U.S. Resource Estimates

U.S. wind energy resource estimates are highly dependent on certain assumptions used to calculate them, and users of those estimates should pay careful attention to the underlying assumptions. Turbine height and capacity factor assumptions can have major impacts on wind resource estimates. For example, winds are generally stronger at greater heights above the ground. As a result, wind resource estimates at 100 meters are likely to be greater than those at 50 meters.

Wind energy resources in the United States are typically categorized as either "onshore" or "offshore." According to National Renewable Energy Laboratory (NREL) estimates, onshore wind electricity generation potential for the 48 contiguous United States ranges from 22.5 million gigawatthours to 46.9 million gigawatthours annually.[14] Wind resources can vary state by state and region by region. Based on NREL estimates, the largest onshore U.S. wind energy resources are located in the middle of the country (see **Figure 4**).

[14] In February 2010, NREL and AWS Truepower released estimates for windy land area and wind energy potential for the 48 contiguous United States. A revision to these estimates that includes data for Alaska and Hawaii was released in April 2011. This is the first comprehensive update of wind energy potential since 1993. The NREL AWS study evaluates three gross (no system losses included) capacity factor assumptions (30%, 35%, and 40%) and two hub heights (80 meters and 100 meters). NREL/AWS also considered certain land area exclusions such as parks, urban areas, and others. Study results, maps, and data tables available at http://www.windpoweringamerica.gov/wind_maps.asp.

Figure 4. U.S. Onshore Wind Energy Resources, 80 Meter Turbine Height



Source: http://www.windpoweringamerica.gov/wind_maps.asp.

NREL has also calculated estimates for U.S. offshore wind energy resources.[15] Based on NREL estimates, offshore wind energy resource potential may range between 10 million GWh and 14.5 million GWh annually.[16] **Figure 5** illustrates how offshore wind energy resources vary by location. However, in its February 2011 National Offshore Wind Strategy report, the DOE EERE states that "the offshore wind resource is not well characterized."[17] This uncertainty indicates that additional work may be needed to more accurately assess U.S. offshore wind potential.

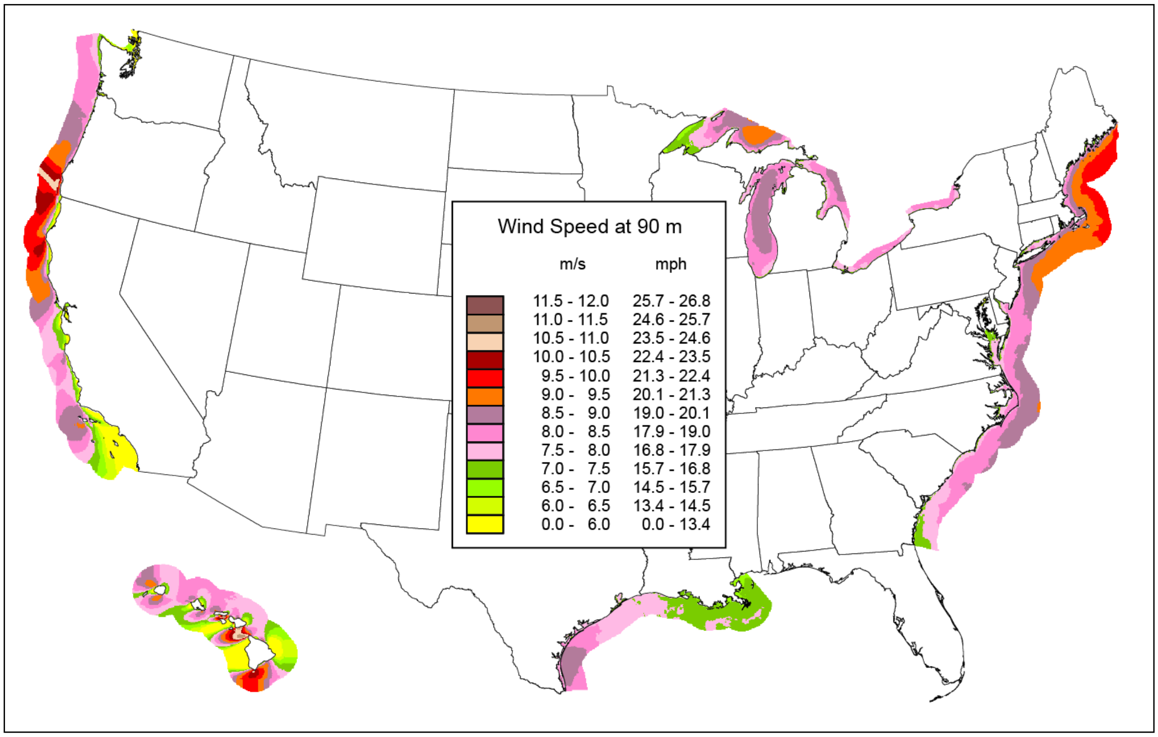
[15] NREL's offshore wind study does not take into account any potential area exclusions. The offshore wind study also does not include estimates for Florida, Mississippi, Alabama, or Alaska. For more information see Marc Schwartz, Donna Heimiller, Steve Haymes, and Walt Musial, "Assessment of Offshore Wind Energy Resources for the United States," National Renewable Energy Laboratory, June 2010, available at http://www.windpoweringamerica.gov/pdfs/offshore/offshore_wind_resource_assessment.pdf.

[16] Gigawatthour estimates for offshore wind energy resources were calculated by CRS by applying average capacity factor assumptions of 30% and 40% to megawatt installed capacity estimates from NREL.

[17] "A National Offshore Wind Strategy: Creating an Offshore Wind Energy Industry in the United States," U.S. Department of Energy, Energy Efficiency and Renewable Energy, February 2011, available at http://www1.eere.energy.gov/windandhydro/pdfs/national_offshore_wind_strategy.pdf.

Figure 5. U.S. Offshore Wind Energy Resources, 90 Meter Turbine Height

(Excluding Alaska)



Source: http://www.windpoweringamerica.gov/windmaps/offshore.asp.

Technology and Cost Considerations

Onshore wind energy conversion technology is generally considered to be commercially available[18] and many projects are able to attract debt and equity investment capital for project development. General Electric and Siemens were the top two manufacturers of wind turbines installed in the U.S. during 2010.[19] Typical wind turbines have a rated capacity between 1 megawatt and 3 megawatts, and the general industry trend is to continue increasing the size and capacity of individual wind turbines in order to operate at greater heights (taller towers) and realize economies of scale by generating more watthours from a single unit. Offshore wind energy technology faces some technical challenges associated with operating in a corrosive marine environment and installation of equipment at various water depths. The Department of Energy (DOE) operates a Wind Power Program aimed at wind research and development needs.[20]

[18] For the purpose of this report, "commercially available" refers to renewable electricity generation technologies that have achieved an adequate amount of operational time that allows for performance validation, accurate reliability assessments, and an understanding of actual operations and maintenance requirements. These commercialization parameters are typically validated by an independent engineering firm. This independent validation is typically necessary for technologies, and projects that use these technologies, to obtain debt and equity for project development. Furthermore, commercially available technologies typically have an established supply chain of companies that can provide equipment to meet certain project and technology performance specifications.

[19] American Wind Energy Association (AWEA) U.S. Wind Industry Annual Market Report Year Ending 2010.

[20] More information on DOE's Wind Power program is available at http://www1.eere.energy.gov/windandhydro/wind_power.html.

The cost of wind-generated electricity can vary based on a number of technology, performance, operational, and financial factors. These factors are discussed in the "Levelized Cost of Energy" section below. Assumptions made for these factors can result in significant differences among cost-of-electricity estimates. In its Annual Energy Outlook 2011, EIA estimates onshore wind electricity costs to range from $82-$115 per megawatthour (MWh) and offshore electricity costs between $187-$349 per MWh.[21] **Figure 12** provides a comparison of costs for conventional (fossil and nuclear) and renewable electricity generation.

Solar

U.S. Resource Estimates

Every U.S. locale receives sunlight during a calendar year, of course, but the amount of radiation that reaches a given point at a particular time can vary based on factors that might include geography (including latitude), time of day, season, landscape, and weather.[22] Two authoritative sources for U.S. solar resources are the National Solar Radiation Database (NSRDB), and NREL and State University of New York at Albany (SUNYA) satellite-derived solar resources.[23]

Quantifying solar resource data, in terms of annual electricity generation potential, is complicated by several factors.[24] First, two different methods are used for capturing and converting solar energy into electricity: (1) concentrating solar power (CSP), and (2) photovoltaic (PV) solar power.[25] Second, solar radiation has different components that may be better suited for different collector types.[26] Third, different system configurations are used to collect data and calculate solar resource estimates.[27] Finally, different types of CSP and PV technologies, with different cost, efficiency, and performance characteristics, are available for solar energy conversion.[28]

[21] Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011, U.S. Energy Information Administration, available at http://www.eia.gov/oiaf/aeo/electricity_generation.html.

[22] An overview of solar resources is provided by the Department of Energy at http://www.eere.energy.gov/basics/renewable_energy/solar_resources.html.

[23] For a comprehensive summary of current solar resource assessment information, see "Report to Congress on Renewable Energy Resource Assessment Information for the United States," U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2011.

[24] The approach used to quantify annual solar electricity generation potential was based on input from experts at NREL and Sandia National Laboratory. If different methodologies for calculating solar resource potential, such as quantifying the total amount of solar radiation exposure on the surface area of the United States, are employed, results may be different (likely much higher) than the summary data presented in this section.

[25] For an overview of CSP technology see http://www.eere.energy.gov/basics/renewable_energy/csp.html. For an overview of PV technology see http://www.eere.energy.gov/basics/renewable_energy/photovoltaics.html.

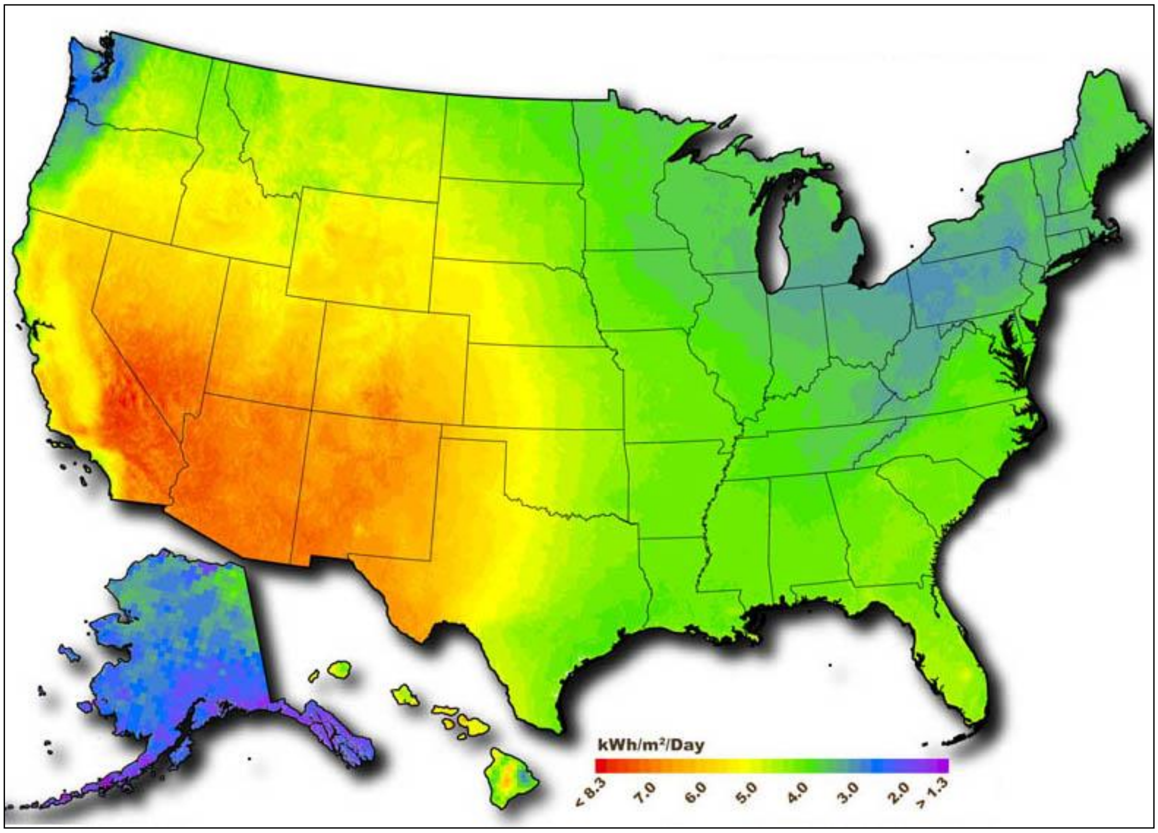
[26] Three solar radiation components are typically measured and reported: (1) direct beam solar radiation, (2) diffuse solar radiation, and (3) global solar radiation (the sum of direct beam and diffuse). CSP systems are able to use only direct beam solar radiation. PV systems are able to use both direct beam and diffuse radiation. More detail regarding solar radiation components is available at http://www.eere.energy.gov/basics/renewable_energy/solar_resources.html.

[27] Solar energy system configurations may include (1) south-facing flat-plate collectors at various tilt angles, (2) one-axis flat-plate tracking, (3) two-axis flat-plate tracking collectors, and (4) direct-beam one and two-axis tracking concentrating collectors. For more information regarding solar system configurations see, D. Renne, R. George, S. Wilcox, T. Stoffel, D. Myers, and D. Heimiller, "Solar Resource Assessment," National Renewable Energy Laboratory, February 2008, available at http://www.nrel.gov/docs/fy08osti/42301.pdf.

[28] For a description of various CSP technologies, see http://www.solarpaces.org/CSP_Technology/csp_technology.htm. For a description of various PV technologies, see http://solarbuzz.com/going-solar/understanding/technologies.

CSP resources vary throughout the country, with most of the highest quality resource located in the southwestern United States (see **Figure 6**). CSP electricity generation is typically better suited for large-scale (greater than 10 MW) power generation projects. NREL and Sandia National Laboratories estimate that U.S. CSP electricity generation potential is approximately 16.3 million GWh.[29] This estimate is the result of applying a set of filters to existing CSP resource data in order to calculate CSP electricity generation potential.[30] NREL and Sandia CSP estimates include electricity generation potential in seven U.S. states.[31]

Figure 6. U.S. Concentrating Solar Resource



Source: National Renewable Energy Laboratory (NREL), available at http://www.nrel.gov/gis/images/map_csp_national_lo-res.jpg.

Notes: Annual average direct normal solar resource data are shown. The data for Hawaii and the 48 contiguous states are 10km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005. The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003); $kWh/m^2/Day$ = kilowatthour per square meter per day.

Photovoltaic resources also vary throughout the country and, much like CSP, the highest quality PV resources are located in the southwestern United States (see **Figure 7**). PV systems offer

[29] Tom Mancini, "CSP Overview," Sandia National Laboratories.

[30] *Ibid.* Filters applied to derive these analysis results include (1) sites with >6.75 $kwh/m^2/day$ direct normal insolation, (2) excluding environmentally sensitive lands, major urban areas, etc., (3) removing land with slope >1%, 4) only including contiguous areas >$10km^2$. Changing these filters (i.e. reducing the direct normal insolation threshold) would yield different results.

[31] *Ibid.* Arizona, California, Colorado, Nevada, New Mexico, Texas, and Utah.

flexibility in terms of project size and can be used for residential, commercial, and utility-scale applications. As of July 2011, estimates of the technically available and economically recoverable solar photovoltaic resource, in terms of annual GWh, were not available. However, previous work by NREL provides some indication about solar generation potential. NREL researchers analyzed land-use requirements for generating 100% of U.S. electricity and estimated that 0.6% of total U.S. land area would be needed to satisfy current demand load using a "base system configuration."[32] NREL has also estimated land-use requirements for a variety of other system configurations.[33] Calculating total PV generation based on this NREL analysis is somewhat complicated, but it may be reasonable to assume that solar PV could theoretically generate 10 times the amount of current U.S. demand, although realizing this amount of electricity generation may be limited by several factors, particularly cost and power system integration.[34] Extrapolating from the NREL analysis, U.S. annual solar PV generation potential may be equal to approximately 40 million GWh. NREL has also evaluated the generation potential of residential and commercial rooftop PV systems and estimates that, under a base-case scenario, approximately 819,000 GWh of electricity could be generated each year using existing rooftop space.[35]

Technology and Cost Considerations

The most commonly used CSP technology in the United States is the parabolic trough. Of the 509 megawatts of U.S. installed CSP capacity, approximately 98% uses parabolic trough technology.[36] Crystalline silicon is the most commonly used PV technology.[37] While some CSP and PV technologies might be considered commercially available, there are a number of research and development activities within CSP and PV markets.[38] Generally speaking, most CSP and PV R&D work is focused on improving system-level efficiencies and reducing system costs. Storage, demand response, and other "smart-grid" technologies may further enable large-scale solar deployment.[39]

The cost of solar electricity has been a challenge faced by both CSP and PV technologies. Solar electricity, according to the Energy Information Administration, is the highest-cost source of

[32] P. Denholm and R. Margolis, "Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States," Energy Policy 36, 3531-3543, 2008.

[33] For more information see P. Denholm and R. Margolis, "Impacts of Array Configuration on Land-Use Requirements for Large-Scale Photovoltaic Deployment in the United States," NREL, Conference paper presented at SOLAR 2008—American Solar Energy Society (ASES), May 3-8, 2008.

[34] Telephone interview with Robert Margolis at NREL.

[35] P. Denholm and R. Margolis, "Supply Curves for Rooftop Solar PV-Generated Electricity for the United States," National Renewable Energy Laboratory, November 2008, available at http://www.nrel.gov/docs/fy09osti/44073.pdf.

[36] The remaining 2% of installed capacity consists of power tower, linear fresnel, and dish-stirling technologies. See Tom Mancini, "CSP Overview," Sandia National Laboratories.

[37] For more information about crystalline solar cells, see Y.S. Tsuo, T.H. Wang, and T.F. Ciszek, "Crystalline-Silicon Solar Cells for the 21st Century," NREL, May 1999, available at http://www.nrel.gov/docs/fy99osti/26513.pdf.

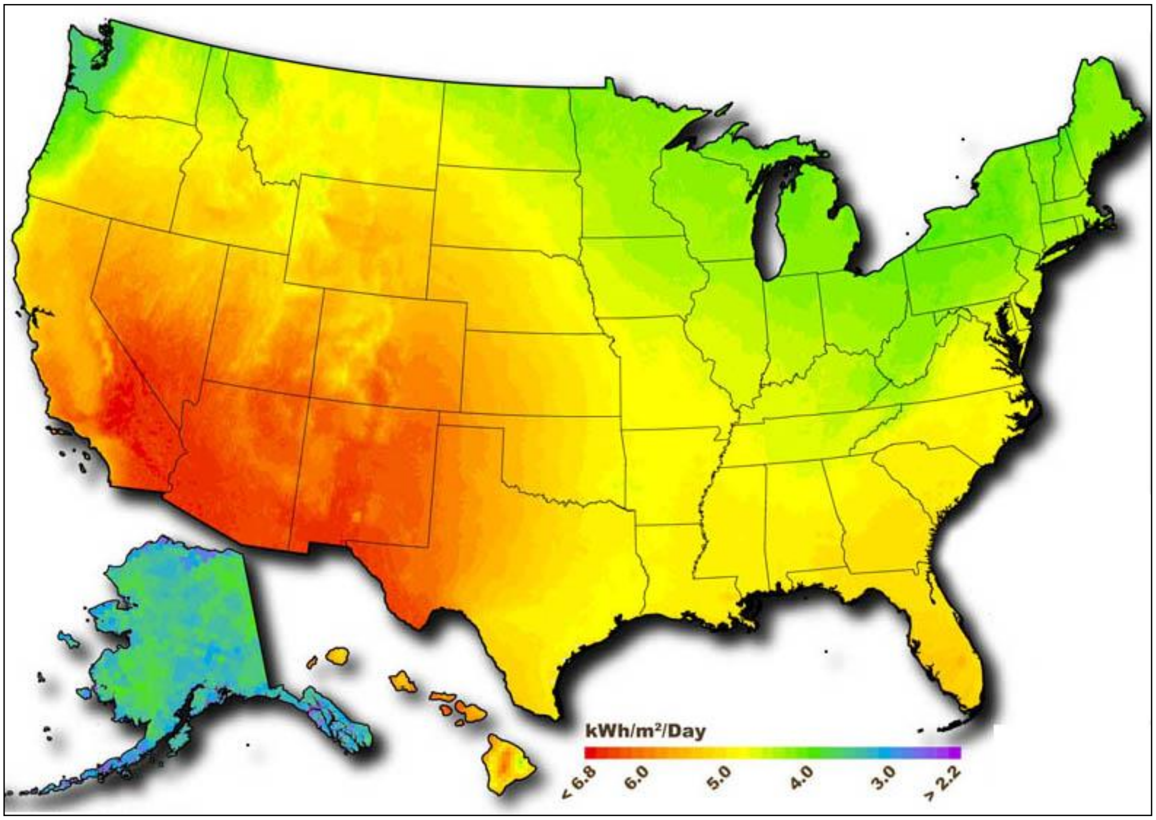
[38] More information about DOE CSP R&D programs and projects is available at http://www1.eere.energy.gov/solar/csp_program.html. More information about DOE PV R&D programs and projects is available at http://www1.eere.energy.gov/solar/photovoltaics_program.html.

[39] For more information on electrical energy storage, see "Energy Storage: Program Planning Document," Department of Energy, Office of Electricity Delivery and Energy Reliability, February 2011, available at http://www.oe.energy.gov/DocumentsandMedia/OE_Energy_Storage_Program_Plan_Feburary_2011v3.pdf.

For more information on "smart-grid," see "The Smart Grid: An Introduction," Department of Energy, available at http://www.oe.energy.gov/DocumentsandMedia/DOE_SG_Book_Single_Pages(1).pdf.

electricity generation, with CSP costs ranging from $192-$642 per MWh and PV costs ranging from $159-$324 per MWh.[40] DOE is funding an initiative, known as the SunShot program, which aims to reduce the cost of PV electricity generation to $60 per MWh.[41] **Figure 12** provides a comparison of costs for conventional (fossil and nuclear) and renewable electricity generation.

Figure 7. U.S. Photovoltaic Solar Resource



Source: National Renewable Energy Laboratory (NREL), available at http://www.nrel.gov/gis/images/map_pv_national_lo-res.jpg.

Notes: Annual average solar resource data are shown for a tilt-latitude collector. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005. The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003); kWh/m²/Day = kilowatthour per square meter per day.

Geothermal

U.S. Resource Estimates

Geothermal energy is present throughout the entire country, with most of the highest-quality geothermal resources generally located in the western United States, Alaska, and Hawaii.[42]

[40] For more information on EIA assumptions and calculation methodology see http://www.eia.gov/oiaf/aeo/electricity_generation.html.

[41] More information about DOE's SunShot initiative can be found at http://www1.eere.energy.gov/solar/sunshot/.

[42] There are three general applications for geothermal energy: (1) electricity production, (2) direct heating, and (3) geothermal (ground source) heat pumps. Typically, the application selected depends in part on the resource

However, all states may have geothermal electricity generation potential through the use of enhanced, or engineered, geothermal systems (EGS) technology.[43] USGS, NREL, and the Massachusetts Institute of Technology (MIT) each have published estimates for U.S. geothermal electricity generation. Generally, geothermal electricity generation resources are classified into three categories: (1) identified resources, (2) undiscovered resources, and (3) enhanced geothermal systems.[44] **Table 3** provides a summary of USGS, NREL, and MIT potential geothermal capacity estimates for these resource types along with annual electricity generation potential in GWh.

Table 3. U.S. Geothermal Electricity Generation Potential

	Identified Resource		Undiscovered Resource		Enhanced Geothermal Systems	
	Low	High	Low	High	Low	High
USGS[a]						
Capacity (MW-e)	3,675	16,457	7,917	73,286	345,100	727,900
Electricity Generation[b] (GWh/yr)	29,618	132,630	63,805	590,627	834,369	1,759,888
NREL[c]						
Capacity (MW-e)	n/a	6,390	n/a	30,030	n/a	15,000,913
Electricity Generation[b] (GWh/yr)	n/a	51,498	n/a	242,018	n/a	36,268,607
MIT[d]						
Capacity (MW-e)	n/a	n/a	n/a	n/a	1,249,000	12,486,000
Electricity Generation[b] (GWh/yr)	n/a	n/a	n/a	n/a	3,019,782	30,188,151

Source: U.S. Geological Survey, National Renewable Energy Laboratory, MIT. See specific references below.

Notes: Electricity generation potential estimates represent what might be technically recoverable and do not include any filters for economic factors. "Identified" and "Undiscovered" resources generally represent conventional geothermal resources where naturally occurring conditions (high temperature and permeability)

temperature. Geothermal electricity production typically uses moderate temperature (90-150°C) and high temperature (greater than 150°C) resources. Direct heating typically uses low temperature (less than 90°C) resources. Heat pump applications utilize shallow ground temperatures for heating and cooling. Geothermal energy for electricity production is the focus of this report. More information about these three applications is available at http://www.nrel.gov/learning/re_geothermal.html. For more information about low temperature geothermal energy resources, see M. Reed, R. Mariner, C. Brook and M. Sorey, "Selected Data For Low-Temperature (Less Than 90°C) Geothermal Systems In The United States; Reference Data For U.S. Geological Survey Circular 892," U.S. Geological Survey, 1983, available at http://energy.usgs.gov/PDFs/USGS_Open-File%20Report%2083-250_1983.pdf.

[43] "Report to Congress on Renewable Energy Resource Assessment Information for the United States," U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2011.

[44] NREL categorizes geothermal resources into four categories: (1) identified, (2) undiscovered, (3) near-hydrothermal field EGS, and (4) deep EGS. For purposes of comparison, CRS combined "near-hydrothermal field EGS" and "deep EGS" and classified them both as "Enhanced Geothermal Systems."

allow for extraction of geothermal energy. "Enhanced Geothermal Systems" require engineering of rock permeability to create geothermal energy extraction conditions. Electricity generation numbers were calculated by CRS using a 92% capacity factor for each geothermal capacity estimate. USGS low estimates for each resource category represent resources that have a 95% probability of being available. USGS high estimates for each resource category represent resources that have a 5% probability of being available. NREL analysis provided a single number for identified, undiscovered, and EGS resource estimates, respectively. The MIT study focused on the potential of EGS in the United States. The large difference between MIT's low and high estimates reflect an assumption made for the EGS energy recovery factor (2% for the low estimate, 20% for the high estimate).

a. "Assessment of Moderate- and High-Temperature Geothermal Resources of the United States," U.S. Geological Survey, 2008, available at http://pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf.

b. Annual electricity generation potential assumes that all potential geothermal resources are developed and operating. This is highly unlikely since EGS systems may result in resource depletion over a 30-40 year operating life; regeneration of this resource is estimated to take approximately 100 years. As a result, EGS estimates for GWh/yr were discounted by a factor of 0.3 in order to calculate sustainable electricity generation potential based on a 30-year depletion and 100-year regeneration profile

c. C. Augustine, K. Young, and A. Anderson, "Updated U.S. Geothermal Supply Curve," National Renewable Energy Laboratory, Conference Paper presented at Stanford Geothermal Workshop, February 1, 2010, available at http://www.nrel.gov/docs/fy07osti/41073.pdf.

d. "The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century," Massachusetts Institute of Technology, 2006, available at http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf.

MW-e = megawatt electrical generating capacity.

GWh/yr = gigawatthours per year.

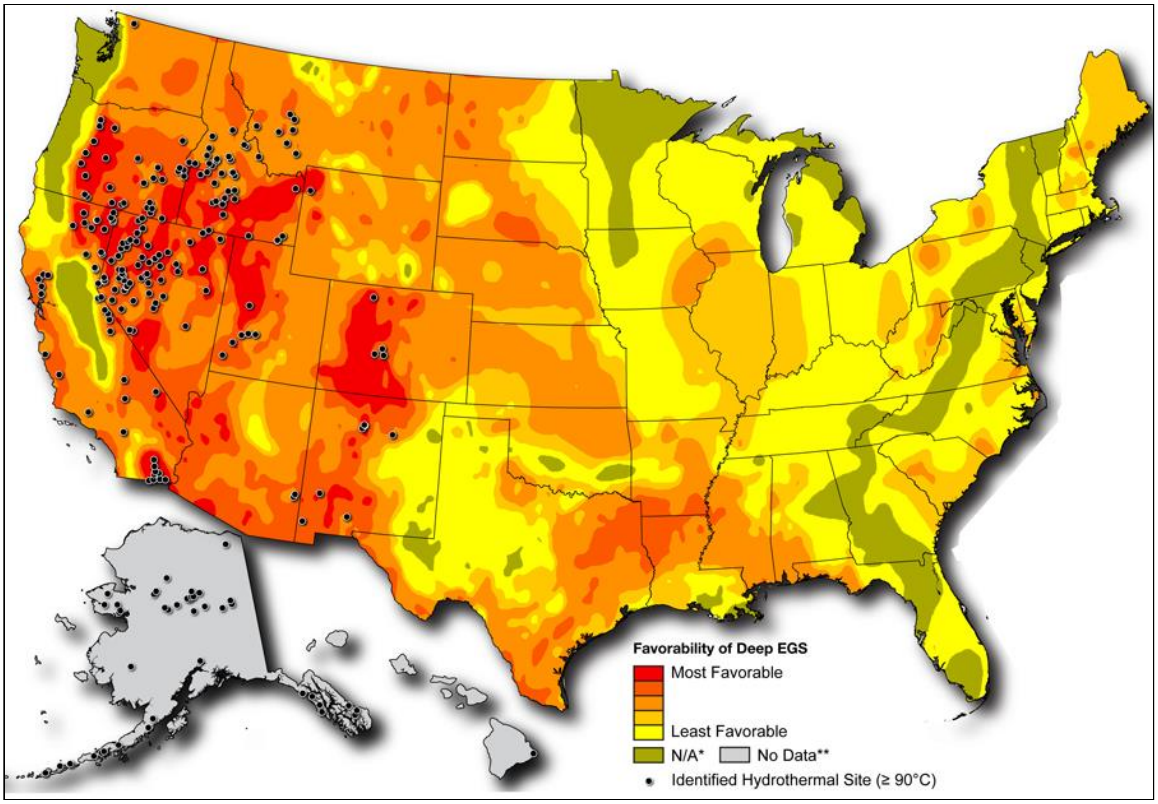
USGS, NREL, and MIT each have a different estimate for U.S. geothermal electricity generation potential, especially with regard to enhanced geothermal systems. Two primary factors account for the differences in estimates: (1) USGS estimates are confined to western U.S. states, Hawaii, and Alaska, while NREL and MIT estimates include potential electricity generation from all 50 states, and (2) USGS estimates are for resource depths between 3 kilometers (km) and 6 km, while NREL and MIT estimates are for resource depths between 3 km and 10 km.[45] This disparity in resource estimates illustrates how assumptions can significantly alter the assessment results.

Figure 8 shows conventional geothermal sites and the estimated relative suitability of EGS geothermal energy recovery throughout the U.S.

[45] Phone interview with Chad Augustine at NREL.

Figure 8. Geothermal Resource of the United States

(Locations of identified hydrothermal sites and favorability of deep enhanced geothermal systems [EGS])



Source: NREL, available at http://www.nrel.gov/gis/images/geothermal_resource2009-final.jpg.

Notes: Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources. Source data for deep EGS includes temperature at depth from 3 to 10 km provided by Southern Methodist University Geothermal Laboratory (Blackwell & Richards, 2009) and analysis (for regions with temperatures ≥150°C) performed by NREL (2009). Source data identified hydrothermal sites from USGS Assessment of Moderate- and High-Temperature Geothermal Resources of the United States (2008).

* "N/A" regions have temperatures less than 150°C at 10 km depth and were not assessed for deep EGS potential.

** Temperature at depth data for deep EGS in Alaska and Hawaii not available.

Technology and Cost Considerations

For conventional hydrothermal geothermal resources, four commercially available technologies are available for generating electricity: (1) flash power plants, (2) dry steam power plants, (3) binary power plants, and (4) flash/binary combined cycle.[46] As of April 2011, U.S. geothermal installed capacity was 3,102 MW, which represents approximately 0.3% of total U.S. electricity capacity. In 2009, 15,009 GWh of electricity was generated from geothermal energy sources. The majority of existing geothermal capacity is located in California.[47] Enhanced Geothermal Systems (EGS) technology could potentially enable large-scale deployment of economically recoverable

[46] Geothermal Energy Association, more information available at http://geo-energy.org/Basics.aspx.

[47] Geothermal Energy Association, more information available at http://geo-energy.org/plants.aspx.

geothermal electricity generation.[48] However, EGS technology has not been demonstrated at scale and is not yet commercially available.[49]

Several factors can influence the cost of geothermal electricity. These factors include the resource quality (temperature and volume), resource depth, drilling costs, and geothermal equipment costs. EIA estimates that the levelized cost of energy (LCOE) for conventional geothermal electricity ranges from $92/MWh to $116/MWh.[50] **Figure 12** provides a comparison of costs for conventional (fossil and nuclear) and renewable electricity generation. NREL has also estimated geothermal electricity LCOE and concluded that, depending on the total amount of capacity installed, geothermal (conventional and EGS) electricity costs could range between $50/MWh and $1,200/MWh (2008 US$).[51] Based on these cost of energy estimates, NREL indicates that the amount of EGS resource "that can be economically produced is likely much smaller" than the total resource potential.[52]

Hydroelectric

U.S. Resource Estimates

Hydropower is currently the largest source of renewable electricity production in the United States. In 2010, approximately 257,000 GWh was generated from hydropower resources, equal to roughly 7% of total U.S. electricity generation.[53] Hydropower can be generated in many ways. For the purpose of this report, hydropower refers to "conventional" hydropower[54] and does not include hydrokinetic energy, ocean energy, or pumped storage.[55]

---

[48] An overview of Enhanced Geothermal Systems (EGS) technology is available at http://www1.eere.energy.gov/geothermal/pdfs/egs_basics.pdf.

[49] The Department of Energy has established EGS commercialization programs. More information available at http://www1.eere.energy.gov/geothermal/enhanced_geothermal_systems.html.

[50] For more information on EIA assumptions and calculation methodology see http://www.eia.gov/oiaf/aeo/electricity_generation.html.

[51] C. Augustine, K. Young, and A. Anderson, "Updated U.S. Geothermal Supply Curve," National Renewable Energy Laboratory, Conference Paper presented at Stanford Geothermal Workshop, February 1, 2010, available at http://www.nrel.gov/docs/fy07osti/41073.pdf.

NREL LCOE estimates are in 2008 US$.

[52] Ibid.

[53] Energy Information Administration, more information available at http://www.eia.gov/cneaf/solar.renewables/page/hydroelec/hydroelec.html.

[54] "Conventional" hydropower resource assessments typically include large hydropower dams, increasing capacity at existing facilities, non-powered dams, small hydro, and low-power hydro. Pumped storage hydroelectricity generation potential is not included in the resource estimates included in this report.

[55] Pumped storage generation potential was not included in the resource assessment literature reviewed for this report. However, pumped-storage projects are being developed and the Federal Energy Regulatory Commission (FERC) has issued pre-permits for about 33 gigawatts of pumped storage capacity (see http://www.ferc.gov/industries/hydropower/gen-info/licensing.asp). The business case for pumped storage might be viewed as an arbitrage opportunity whereby water is pumped to a reservoir when energy prices are low, and the stored water is used to generate electricity when energy prices are high or an opportunity exists to receive a financial premium for stand-by or firm power. According to EIA, more energy is required to pump water into a storage reservoir than is generated when electricity is produced by releasing the stored water. However, pumped storage facilities can provide valuable ancillary on-demand energy production services for electricity grid operators. For more information see http://www.ferc.gov/industries/hydropower/gen-info/regulation/pump.asp.

Since 1998, several Idaho National Laboratory (INL) reports have estimated the potential to develop new hydropower generation capacity. Three of those reports trace a time-wise increase in the estimates of potential generation capacity: 30 GW (1998),[56] 43 GW (2003),[57] and 60 GW (2006).[58] A review of the INL reports revealed that estimates differed with regard to the hydropower categories included in the calculations.[59] After sorting through the studies and attempting to remove duplicative and non-relevant data, CRS calculated additional hydropower potential to be approximately 65 gigawatts, which equates to approximately 284,700 GWh of additional annual electricity generation potential.[60] A 2007 report by the Electric Power Research Institute (EPRI) estimated that additional hydropower capacity potential was equal to 62.3 gigawatts.[61] However, recently published Oak Ridge National Laboratory (ORNL) resource potential estimates for non-powered dams may increase the total hydropower resource assessment by as much as 12.6 gigawatts.[62]

Figure 9 provides summary information about the location of existing and potential hydroelectricity facilities in the United States.

---

[56] A. Conner, J. Francfort, and B. Rinehart, "U.S. Hydropower Resource Assessment Final Report," Idaho National Engineering and Environmental Laboratory, December 1998, available at http://hydropower.inl.gov/resourceassessment/pdfs/doeid-10430.pdf.

[57] D. Hall, R. Hunt, K. Reeves, and G. Carroll, "Estimation of Economic Parameters of U.S. Hydropower Resources," Idaho National Engineering and Environmental Laboratory, June 2003, available at http://hydropower.inl.gov/resourceassessment/pdfs/project_report-final_with_disclaimer-3jul03.pdf.

[58] D. Hall, K. Reeves, J. Brizzee, R. Lee, G. Carroll, and G. Sommers, "Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants," Idaho National Laboratory, January 2006, available at http://hydropower.inl.gov/resourceassessment/pdfs/main_report_appendix_a_final.pdf. Note: This report quantified hydropower resource potential as megawatts-annual (MWa) based on a 50% capacity factor assumption. As a result, CRS had to convert MWa estimates to megawatts (MW) in order to have resource estimates on an equivalent basis.

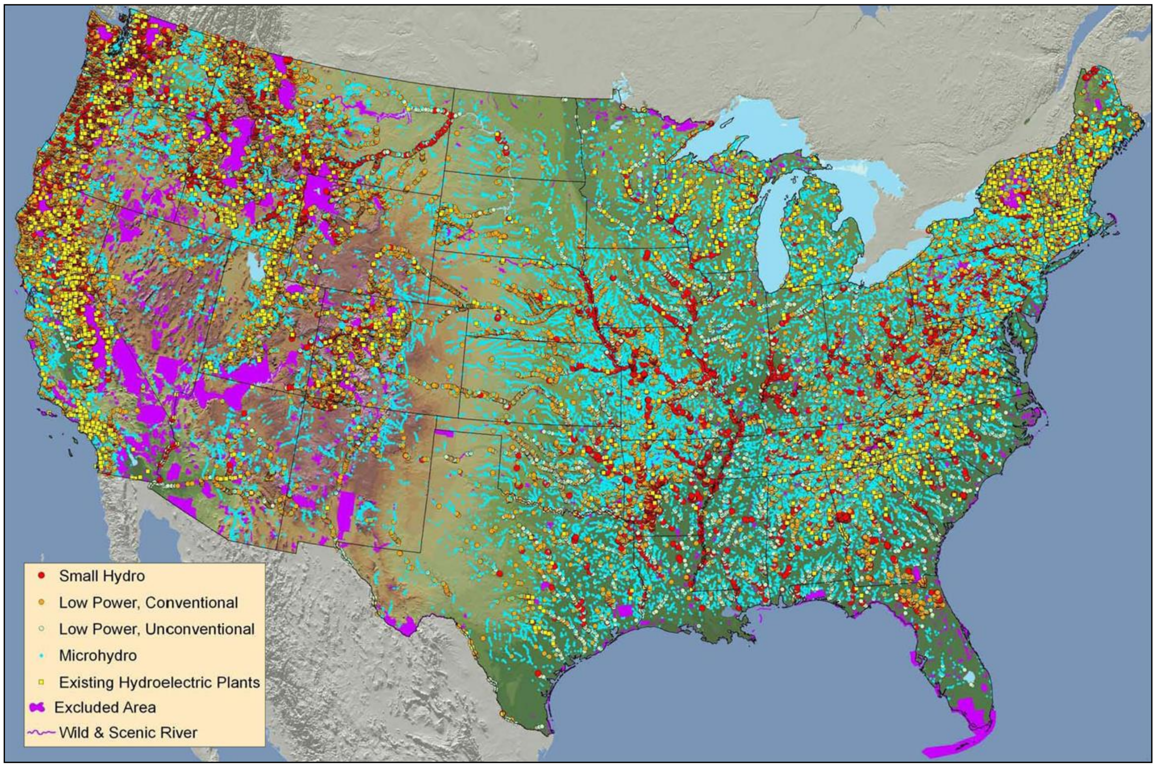
[59] The primary difference between the reports was the inclusion of low-power (<1MW) hydropower resources in the INL 2006 report.

[60] Electricity generation potential assumes a 50% capacity factor.

[61] "Assessment of Waterpower Potential and Development Needs," Electric Power Research Institute, 2007, available at http://www.aaas.org/spp/cstc/docs/07_06_1ERPI_report.pdf.

[62] Presentation by Brennan T. Smith to the National Hydropower Association Annual Conference, "U.S. Hydropower Fleet and Resource Assessments," Oak Ridge National Laboratory, April 5, 2011, available at http://hydro.org/wp-content/uploads/2011/04/Brennan-Smith-PPT_NHA_April2011_Final.pdf.

Figure 9. Existing and Potential Hydropower Projects in the Lower 48 United States



Source: DOE. "Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants," DOE, Office of Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies, January 2006, available at http://www1.eere.energy.gov/windandhydro/pdfs/doewater-11263.pdf.

Notes: Alaska and Hawaii were included in the DOE study, but were not included in the accompanying map. DOE study results indicate that Alaska may have the potential to increase its hydropower capacity by as much as 16 times and Hawaii was distinguished as the state having the highest concentration (measured as kilowatt-annual per square mile) of hydropower potential.

Technology and Cost Considerations

Hydroelectricity generation in the United States dates back to the 1880s and many technologies are fully commercialized with proven operational performance.[63] However, DOE is pursuing efforts to further improve the performance, economics, and environmental impact of conventional hydropower technologies.[64] Low-head and low-power hydroelectricity technology that might be used in constructed waterways, such as canals, may require additional research, development, and demonstration before being commercially available.[65]

---

[63] For more information on the history of hydroelectricity in the United States see http://www1.eere.energy.gov/windandhydro/hydro_history.html.

For an overview of hydroelectricity technologies see CRS Report R41089, *Small Hydro and Low-Head Hydro Power Technologies and Prospects*, by Richard J. Campbell.

[64] For more information, see http://www1.eere.energy.gov/windandhydro/printable_versions/hydro_advtech.html.

[65] DOE, in April 2011, announced $10.5 million of funding for small hydropower technologies that could be deployed in constructed waterways. For more information see http://www.energy.gov/news/10255.htm.

Hydroelectricity is generally considered to be one of the lowest-cost sources of renewable electricity. EIA estimates that the LCOE for new hydroelectricity plants ranges from $59/MWh and $121/MWh.[66] **Figure 12** provides a comparison of costs for conventional (fossil and nuclear) and renewable electricity generation. However, due to their relatively early stage of development, the cost of electricity from low-head and low-power technologies remains somewhat uncertain.

Ocean and Hydrokinetic

U.S. Resource Estimates

Ocean-based energy resources come in several forms, including (1) tidal, (2) wave, (3) current, and (4) thermal (also known as Ocean Thermal Energy Conversion or OTEC).[67] Each ocean energy resource is fundamentally different in terms of the amount of available resources, location of the resource, and the conversion technology used to generate electricity. While a limited number of ocean energy resource assessments are available, the Electric Power Research Institute (EPRI) published resource estimates for wave and tidal energy in 2006.[68] DOE has funded several resource assessments that are not yet available.[69] **Table 4** summarizes some of the resource estimates for different categories of ocean energy.

Table 4. U.S. Ocean Energy Resource Estimates

	Resource Estimate (GWh/year)		
	Low	High	Resource Assessment Status
Wave	255,000	2,100,000	In 2008, DOE awarded a Marine Energy Grant to EPRI to assess U.S. wave energy resources.
Tidal	n/a	6,600	Georgia Tech Research Corporation was awarded a grant from DOE to assess tidal stream energy production potential.
Current	n/a	n/a	DOE awarded a grant to Georgia Tech Research Corporation to create a database of ocean current energy potential.
OTEC	n/a	n/a	DOE awarded a grant to Lockheed Martin in 2009 to conduct global and domestic ocean thermal resource assessments.

[66] See EIA "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011," available at http://www.eia.gov/oiaf/aeo/electricity_generation.html.

[67] For more information regarding these energy production approaches, see "Ocean Energy Technology Overview," Department of Energy, Office of Energy Efficiency and Renewable Energy, July 2009, available at http://www1.eere.energy.gov/femp/pdfs/44200.pdf.

Osmotic, or salinity gradient, power is another possible source of ocean energy. However, this energy production source has not yet been explored or analyzed in great detail. Background on osmotic power is available at http://en.wikipedia.org/wiki/Osmotic_power.

[68] For more information about EPRI's wave energy resource assessment, see http://oceanenergy.epri.com/waveenergy.html. For more information about EPRI's tidal energy resource assessment see http://oceanenergy.epri.com/streamenergy.html.

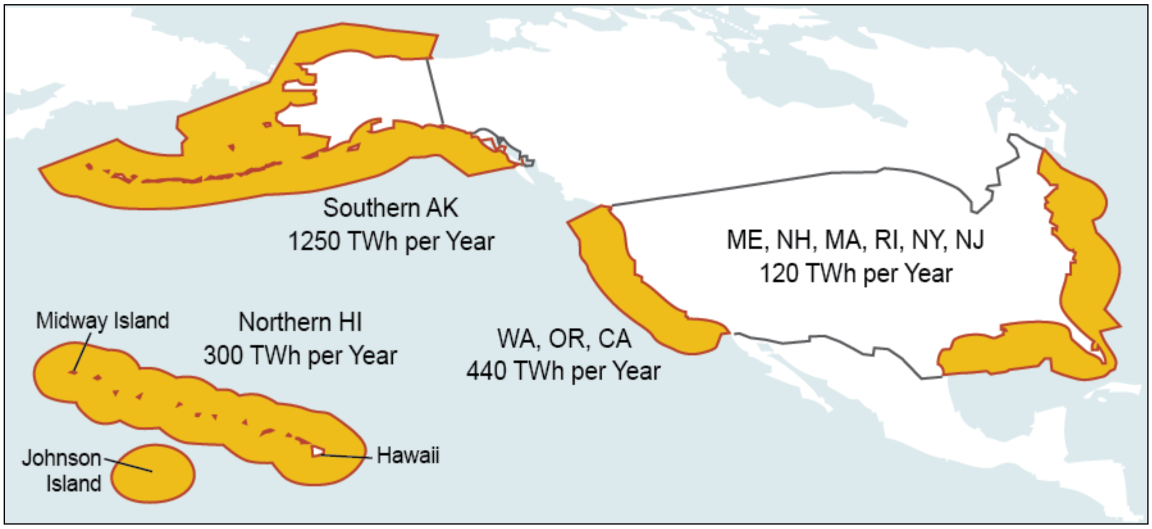
[69] On July 6, 2011 DOE released a database, developed in partnership with the Georgia Institute of Technology, of tidal energy resources in the United States. The interactive database is available online at http://www.tidalstreampower.gatech.edu/.

Source: EPRI (Resource Estimates); "Report to Congress on Renewable Energy Resource Assessment Information for the United States," DOE, Office of Energy Efficiency and Renewable Energy, January 28, 2011.

Notes: n/a = not available.

Figure 10 illustrates the location and magnitude of U.S. wave energy resources. The majority of wave energy potential exists off the coasts of Alaska, Hawaii, and west coast states.

Figure 10. U.S. Wave Energy Resources



Source: R. Bedard, G. Hagerman, M. Previsic, O. Siddiqui, R. Thresher, and B. Ram, "Final Summary Report: Project Definition Study – Offshore Wave Power Feasibility Demonstration Project," Electric Power Research Institute, September 22, 2005, available at http://oceanenergy.epri.com/attachments/wave/reports/009_Final_Report_RB_Rev_2_092205.pdf.

Notes: TWh = terawatthours. 1 TWh = 1,000 gigawatthours.

Hydrokinetic energy, defined as river in-stream energy for the purpose of this report, can be extracted from the natural water flow in rivers. The amount of electricity that can be generated from this energy source is dependent on the volume and velocity of the water resource. A DOE-funded study by New York University estimates that approximately 12.5 GW of hydrokinetic power potential might be possible.[70] Assuming a capacity factor between 30% and 50%, electricity generation potential from hydrokinetic resources may range from 32,850 GWh to 54,750 GWh.[71]

Technology and Cost Considerations

Ocean and hydrokinetic electricity generation technologies might be considered "emerging" as they have yet to operate at a significant commercial scale. Nevertheless, demonstration and commercial deployment of ocean and hydrokinetic projects is being pursued.[72] Many technology

[70] G. Miller, J. Franceschi, W. Lese, and J. Rico, "The Allocation of Kinetic Hydro Energy Conversion Systems (KHECS) in USA Drainage Basins: Regional Resource Potential and Power," New York University, Department of Applied Science, August, 1986.

[71] Capacity factor estimates for hydrokinetic devices were based on data reported by Argonne National Laboratory. See http://teeic.anl.gov/er/hydrokinetic/restech/scale/index.cfm.

[72] As of June 9, 2011, the Federal Energy Regulatory Commission (FERC) had issued 70 preliminary permits for tidal, wave, and inland hydrokinetic projects. For more information, see http://www.ferc.gov/industries/hydropower/indus-act/hydrokinetics.asp.

concepts are being developed and demonstrated, including more than 100 ocean energy devices worldwide, with approximately 30 under development in the United States.[73]

Given the early developmental status of ocean and hydrokinetic electricity production technologies, estimating the levelized cost of energy is challenging.[74] EIA did not include an LCOE estimate for ocean and hydrokinetic electricity generation as part of the Annual Energy Outlook (AEO) 2011.

Biomass

U.S. Resource Estimates

Accurate estimates for biomass electricity generation potential are somewhat challenging because biomass material (forest, agriculture, solid waste, and landfill gases) can be used in a variety of competing ways to include electricity generation, biofuel production, and space heating for residential and commercial buildings.[75] Also, unlike other renewable energy sources, biomass might be considered a managed resource in that the quantity of biomass material available for electricity generation can go up or down based on changes in management practices.[76] As a result, U.S. biomass electricity generation potential is highly dependent on how much biomass is available and how much biomass material is dedicated for this specific use. In 2009 an estimated 54,493 GWh of electricity was generated from biomass, which represented approximately 1.2% of total U.S. net electricity generation.[77]

According to DOE, approximately 190 million tons of biomass are consumed each year, with roughly 25% to 35% of current biomass consumption being used for electricity generation. DOE analysis and reports indicate that the potential may exist to produce about 1.3 billion tons of biomass annually.[78] However, estimating the amount of electricity that might be generated from biomass depends on the amount of biomass material available and on the portion of that material that might be used for electricity generation. **Table 5** provides an estimate for potential generation if DOE's 1.3 billion ton estimate of biomass production were realized.

[73] Remarks by Sean O'Neill, President—Ocean Renewable Energy Coalition, at the 14th Annual Congressional Renewable Energy & Energy Efficiency EXPO + Forum, June 16, 2011.

DOE maintains an on-line database of ocean and hydrokinetic projects worldwide. For more information, see http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx.

[74] Challenges associated with calculating LCOE for ocean and hydrokinetic electricity generation technologies include (1) unknown capital costs, (2) unknown operations and maintenance costs, (3) unknown technology performance characteristics, etc.

[75] For more information on biomass feedstock, see CRS Report R41440, *Biomass Feedstocks for Biopower: Background and Selected Issues*, by Kelsi Bracmort.

[76] Biomass resource management practices may include land utilization intensity, fertilization, using more productive and/or genetically modified crops, among others. NREL's "Billion Ton" study makes some assumptions for resource management changes needed in order to achieve that resource level. For more information, see "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," U.S. Department of Energy and U.S. Department of Agriculture, April 2005, available at http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf.

[77] Energy Information Administration, see http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf.

[78] "Biomass as Feedstock for a Bioenergy And Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," U.S. Department of Energy and U.S. Department of Agriculture, April 2005, available at http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf.

Table 5. Annual U.S. Biomass Electricity Generation Potential

(Based on DOE's 1.3 billion ton biomass resource potential study)

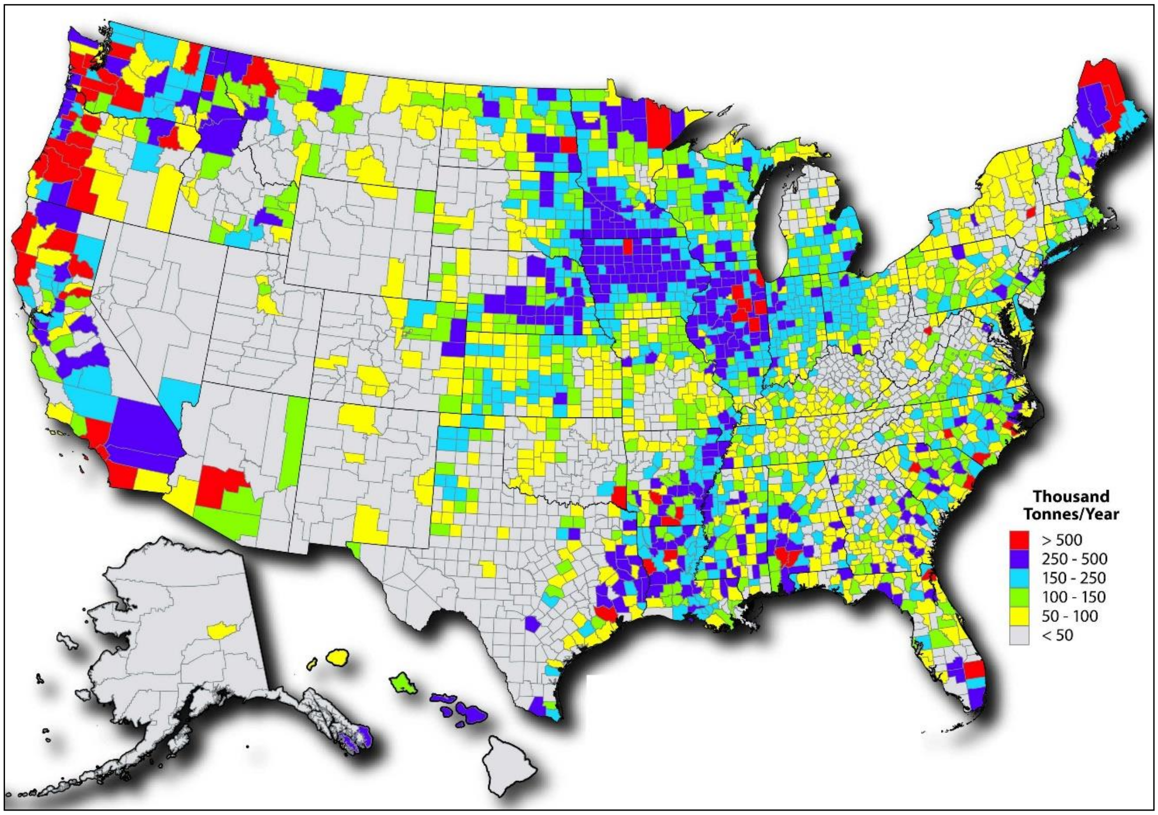
% of 1.3B tons	10%		50%		100%	
	Low	**High**	**Low**	**High**	**Low**	**High**
Electricity Generation (GWh)	125,730	142,880	628,660	714,390	1,257,330	1,428,780

Source: CRS analysis of scenarios based on, "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," U.S. Department of Energy and U.S. Department of Agriculture, April 2005, available at http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf.

Notes: Calculations for this table were based on the following: (1) annual tons consumed for electricity generation, (2) energy content (Btu) per ton of biomass, and (3) biomass-to-electricity conversion efficiency. Estimates of annual tonnage were based on the percentages listed in the table (10%, 50%, and 100%). Energy content per ton of biomass was assumed to be 15 million Btu/ton. Biomass-to-electricity conversion efficiency ranged from 22% to 25%. This range is the reason for "low" and "high" estimates in the table. This conversion efficiency is generally representative of biomass combustion technologies, which have a commercial operating history. Other conversion technologies, such as certain gasification or biological conversion approaches, may have different conversion efficiencies. Since there are competing uses for biomass material, it is unlikely that 100% of the potential biomass resource will be used for electricity generation. The "100%" scenario presented in this table is provided for reference only.

Figure 11 indicates the relative concentration of current biomass resources throughout the United States.

Figure 11. U.S. Biomass Resource Availability



Source: NREL, available at http://www.nrel.gov/gis/images/map_biomass_total_us.jpg.

Notes: This NREL study estimates the biomass resources currently available in the United States by county. It includes the following feedstock categories: crop residues (five year average: 2003-2007), forest and primary mill residues (2007), secondary mill and urban wood waste (2002), methane emissions from landfills (2008), domestic wastewater treatment (2007), and animal manure (2002). For more information on the data development, please refer to http://www.nrel.gov/docs/fy06osti/39181.pdf. Although the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well; the difference is only in the data's time period.

Technology and Cost Considerations

Combustion technologies used to convert biomass to electricity are generally considered commercial, and there are approximately 80 operating biomass electricity generation facilities located in the United States.[79] Nevertheless, using biomass as a feedstock for electricity generation can be challenging because each biomass type has different properties, such as water content, ash content, and energy value.[80] This variability in feedstock quality and characteristics

---

[79] Biomass Power Association, see http://www.usabiomass.org/.

Biomass material might also be co-fired with coal in conventional coal electricity generation facilities. Biomass co-firing with coal may result in improved biomass conversion efficiencies when compared to combusting only biomass. Co-firing biomass with coal may create some technical operating issues associated with tar production and fouling of electricity generating equipment. The degree to which these technical problems might be realized is dependent on the quality of the biomass material being combusted and the percentage of biomass blended and co-fired with coal. For more information see http://www.iea.org/techno/essentials3.pdf.

[80] R. Bain, W. Amos, M. Downing, and R. Perlack, "Highlights of Biopower Technical Assessment: State of the Industry and the Technology," National Renewable Energy Laboratory and Oak Ridge National Laboratory, April

typically must be addressed in order to effectively operate biomass electricity generation equipment. Further, some biomass materials contain certain alkali metal species, such as sodium and potassium, that can potentially impede the operation of electricity generation equipment.[81]

EIA estimates that the levelized cost of energy for biomass electricity ranges from $99.50 per MWh to $133.40 per MWh. Biomass accumulation and transportation and biomass feedstock quality might be considered key cost drivers that can impact the levelized cost of energy for biomass electricity.[82] **Figure 12** provides a comparison of costs for conventional (fossil and nuclear) and renewable electricity generation.

Challenges for Renewable Energy

Each type of renewable energy technology has certain advantages and disadvantages relative to each other and relative to fossil fuel energy sources. An extensive literature exists on these advantages and disadvantages.[83] This part of the report offers brief observations and discussion of certain challenges that might affect the full development and deployment of renewable electricity generation technologies. Many policies directed at renewable energy deployment are designed to address these challenges.

Cost

Perhaps the most fundamental challenge to the deployment of renewable energy is the cost of generating electricity from renewable sources. Energy producers and consumers seek the lowest-cost energy, and fossil fuels have historically been the lowest-cost sources of energy, either through end-use combustion or through the generation of electricity.

Levelized Cost of Energy (LCOE)

A common metric for measuring the financial cost of electricity production is Levelized Cost of Energy, or LCOE.[84] LCOE calculations are typically expressed in terms of dollars per unit of energy. The most common units of energy used for comparing the LCOE of different energy sources are kilowatthour (kWh) and megawatthour (MWh). LCOE estimates can provide a relative comparison of energy generation costs for different energy sources such as coal, natural gas, wind, solar, and others. However, policy makers may want to exercise caution when reviewing and considering LCOE estimates. Reasons for this caution include the following: (1)

2003, available at http://www.nrel.gov/docs/fy03osti/33502.pdf.

[81] Ibid.

[82] For more information about biomass feedstock characteristics see http://www1.eere.energy.gov/biomass/feedstock_databases.html. For more information about biomass feedstock logistics see http://www1.eere.energy.gov/biomass/feedstocks_logistics.html.

[83] See, for example, National Academy of Sciences, National Research Council, *Electricity from Renewable Resources: Status, Prospects, and Impediments*, National Academies Press, 2010.

[84] Terms such as LCOE, Power Purchase Agreement (PPA), contract price, and others, are sometimes used when discussing renewable electricity economics. Each of these terms has different, sometimes multiple, definitions. For example, the Federal Energy Regulatory Commission (FERC) publishes contract prices for electricity, including renewable electricity projects. Published contract prices for wind generated electricity can range between $40/MWh and $60/MWh. Comparing these contract prices with EIA LCOE estimates ($82/MWh minimum) indicates that wind electricity is being sold for less than cost. However, FERC published contract prices may not reflect any value that the wind project might receive by selling renewable energy credits (RECs). It is important to understand what is being reflected in LCOE, PPA, and contract price values.

no agreed-upon or standardized LCOE calculation methodology exists, and methods can be tailored to skew results in favor of a particular technology or resource, (2) assumptions used to calculate LCOE estimates can have a major impact on calculations results, and (3) LCOE estimates may not reflect the variable time-of-day value of electricity generation. For example, electricity at 2 p.m. may have more value than electricity at 2 a.m. Therefore, it is unlikely that LCOE calculations performed by different organizations will be identical. Understanding the methodology and assumptions used is often critical when considering LCOE estimates.

Although there is no standard LCOE calculation method, two fundamental methods are commonly used. One method uses total life cycle costs (capital, operations and maintenance, etc.) and total life cycle energy production to calculate a $/kWh or $/MWh cost of energy.[85] Another method uses a project cash flow model to calculate equity rates of return based on the price of energy paid to the project. Typically, a target equity rate of return, expressed as a percentage, is established and the price per unit of energy is adjusted in order to reach the equity return target.[86] This cash-flow-based methodology is unique in that it may include specific project finance constraints such as debt service coverage ratios, cash reserves, and other factors that may not be reflected in the cost vs. energy production approach.

Furthermore, differences in several key assumptions can significantly alter calculations of LCOE estimates. Assumptions that can impact LCOE estimates include (1) capital costs, (2) operation and maintenance costs, (3) government incentives, (4) capacity factor, (5) financial structure (debt/equity ratio), (6) financial costs for debt and equity, (7) project lifetime, and (8) technology performance degradation. Several key assumptions must be included in each calculation of LCOE estimates. Since different organizations often use different assumptions, the variation in LCOE estimates is not surprising.[87]

For this report, LCOE estimates from the EIA Annual Energy Outlook (AEO) 2011 were used to compare the cost of new electricity generation for various renewable energy resources. **Figure 12** summarizes EIA's range of LCOE estimates for several technologies.[88]

[85] For a detailed description of this LCOE methodology, see "The Drivers of Levelized Cost of Energy for Utility-Scale Photovoltaics," SunPower Corporation, August 14, 2008, available at http://nl.sunpowercorp.be/downloads/SunPower_levelized_cost_of_electricity.pdf.

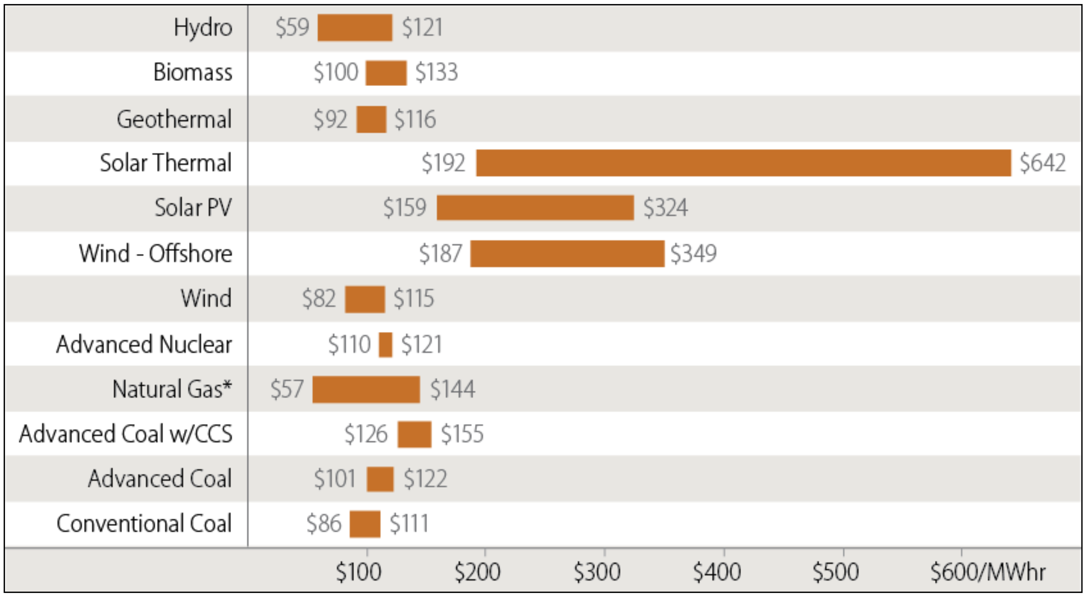
[86] For a description of the cash flow LCOE methodology, see P. Schwabe, S. Lensink, and M. Hand, "IEA Wind Task 26: Multi-National Case Study of the Financial Cost of Wind Energy," IEA Wind, March 2011, available at http://www.ieawind.org/IndexPagePOSTINGS/IEA%20WIND%20TASK%2026%20FULL%20REPORT%20FINAL%203%2010%2011.pdf.

[87] NREL has calculated LCOE estimates for wind and has summarized the sensitivity of LCOE values based on different assumptions. For more information, see K. Cory and P. Schwabe, "Wind Levelized Cost of Energy: A Comparison of Technical and Financing Input Variables," National Renewable Energy Laboratory, October 2009.

[88] For a description of EIA's LCOE methodology and assumptions used for the estimates, see "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011," Energy Information Administration, December 2010, available at http://www.eia.gov/oiaf/aeo/electricity_generation.html.

Figure 12. EIA's Levelized Cost of Energy (LCOE) Estimates for New Plants

(2009 $/Megawatthour)



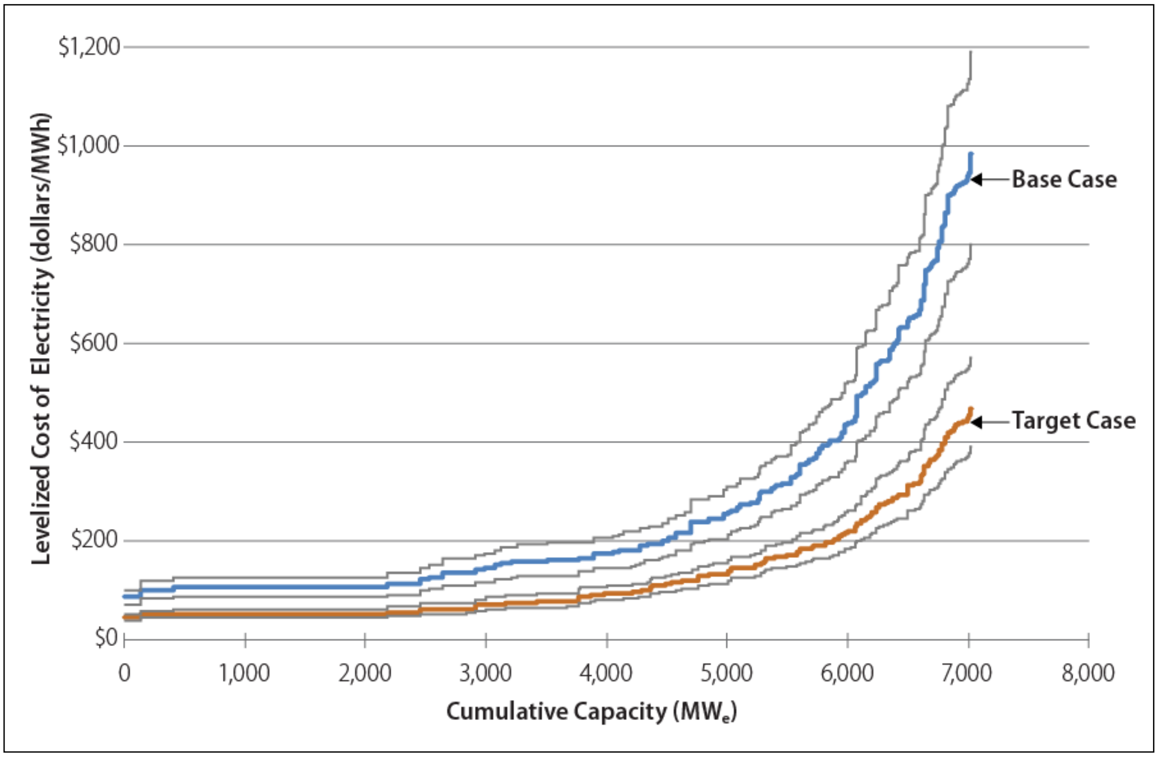
Source: CRS adaptation of EIA's "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011," available at http://www.eia.gov/oiaf/aeo/electricity_generation.html.

Notes: EIA LCOE estimates are for new projects that are would be brought on line in 2016. LCOE estimates do not incorporate any federal or state tax incentives.

* The LCOE range for Natural Gas includes four different technologies: (1) conventional combined cycle, (2) advanced combined cycle, (3) conventional combustion turbine, and (4) advanced combustion turbine.

It is important to note that EIA LCOE estimates reflect only the projected amount of capacity expected to be added to the electricity generation system during the forecast period. Costs for renewable electricity typically follow a supply curve where costs increase as new capacity is installed, which indicates that the lowest-cost capacity will be added first. Geothermal supply curve estimates provide an example to consider. **Figure 13** shows a supply curve for enhanced geothermal electricity costs, developed by NREL. As indicated in the figure, depending on the amount of geothermal capacity installed, the projected LCOE could be as high as $1,000 per MWh. This example of how energy costs can change, as capacity additions increase, further illustrates the importance of understanding all assumptions used for projecting future electricity costs.

Figure 13. NREL Supply Curve for Near-Hydrothermal Field Enhanced Geothermal Systems (EGS) Resource



Source: NREL.

Notes: For more information see C. Augustine, K. Young, and A. Anderson, "Updated U.S. Geothermal Supply Curve," National Renewable Energy Laboratory, Conference Paper presented at Stanford Geothermal Workshop, February 1, 2010, available at http://www.nrel.gov/docs/fy07osti/41073.pdf.

Comparing Fossil and Renewable Energy Costs

The current comparatively low cost of fossil fuel energy, as indicated in EIA's LCOE estimates, may not include any costs associated with the external impacts of fossil fuel consumption, which has been stated this way:

> But some energy costs are not included in consumer utility or gas bills, nor are they paid for by the companies that produce or sell the energy. These include human health problems caused by air pollution from the burning of coal and oil; damage to land from coal mining and to miners from black lung disease; environmental degradation caused by global warming, acid rain, and water pollution; and national security costs, such as protecting foreign sources of oil.[89]

Accurately quantifying social costs of fossil energy associated with health problems, climate change, and others can be difficult and complex. As with all cost calculations, assumptions used for estimating social costs can have a dramatic effect on calculation results. Nevertheless, some groups do attempt to place a value on the social costs of fossil energy as an alternative method for

[89] Union of Concerned Scientists, 2002, The Hidden Cost of Fossil Fuels, available at http://www.ucsusa.org/clean_energy/technology_and_impacts/impacts/the-hidden-cost-of-fossil.html.

comparing the cost of energy from fossil and renewable resources.[90] Furthermore, an Interagency Working Group was created under Executive Order 12866 to estimate the social cost of carbon for regulatory impact analysis.[91] Over time, the costs of mitigating some of these social costs may be placed on the producers or consumers of fossil fuels.

Technology and cost are closely related because renewable energy developers seek technologies that produce energy as inexpensively as possible in order to attain commercially viability. Today, research continues to identify new, more efficient materials and to seek technologies that can be manufactured at lower cost. Improvements continue as new technologies emerge and evolve. Much of the current R&D on renewable technologies aims to reduce the manufacturing cost and the electricity production cost, thereby making renewable electricity more competitive in the marketplace.

Power System Integration

Connecting renewable electricity generation facilities to the electric power grid can raise potential technical challenges. In particular, a high percentage penetration of variable sources—such as solar and wind—can cause serious power quality and reliability problems. The power system requires constant, 24/7 minute-by-minute monitoring and control. The introduction of variable electricity generation may pose power system reliability challenges associated with moment-by-moment balancing of electricity supply and demand.[92] A recent study by the International Energy Agency (IEA) indicates that many existing power systems currently have infrastructure and processes to manage some degree of variability, and these existing assets could potentially be used to manage variable renewable energy resources.[93] However, not all renewable sources of electricity are classified as variable. Biomass, geothermal, and some hydropower sources have the ability to generate electricity on a consistent and predictable basis. As a result, integrating these renewable sources into the power system may not be difficult. However, the inherently variable nature of wind, solar, and some ocean-hydrokinetic electricity may result in significant power system operational challenges if these variable renewable energy sources achieve a high percentage level of penetration.[94]

DOE funded two studies—the Eastern and Western grid interconnection studies—to evaluate the challenges and opportunities associated with significant penetration of variable renewable sources of electricity.[95] The Eastern Wind Integration and Transmission Study assessed the impacts of

---

[90] One study from the Brookings Institution attempts to quantify social costs, per unit of energy produced, associated with energy production. For more information, see M. Greenstone and A. Looney, "A Strategy for America's Energy Future: Illuminating Energy's Full Costs," Brookings Institution, The Hamilton Project, May 2011, available at http://www.brookings.edu/~/media/Files/rc/papers/2011/05_energy_greenstone_looney/05_energy_greenstone_looney.pdf.

[91] For more information, see "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," DOE, Office of Energy Efficiency and Renewable Energy, available at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/sem_finalrule_appendix15a.pdf.

[92] The term "power system," for the purpose of this discussion, includes electricity generators, transmission infrastructure, and electricity consumers. For more information about the North American power system, see http://www.nerc.com/page.php?cid=1|15.

[93] "Harnessing Variable Renewables: A Guide to the Balancing Challenge," International Energy Agency, 2011.

[94] Ibid.

[95] North America has three distinct interconnections: (1) Eastern Interconnect, (2) Western Interconnect, and (3) ERCOT (Electric Reliability Council of Texas) Interconnect. Each interconnect essentially operates as an independent electrical grid system.

integrating wind electricity generation at a 20% to 30% penetration level.[96] The Western Wind and Solar Integration Study evaluated potential power system impacts associated with a 35% penetration comprised of wind (30%) and solar (5%).[97] Both studies concluded that integrating the respective penetration rates of variable renewable electricity is manageable, although accommodating those penetration levels may require large amounts of transmission investment, additional reserve capacity, and modifications to power system operations.

Intermittency and Variability

Some renewable energy sources are intermittent and variable. Geothermal, biomass, and some hydropower energy sources usually can be delivered continuously over time. However, wind power is usable only when the wind blows, solar power is usable only when the sun shines, and some hydroelectric power is usable only when water is available to flow through the turbines, so the production of renewable electricity from those sources varies over a period of minutes, hours, days, or months. In addition, wind speed may vary over a period of seconds, minutes, or hours, and solar energy may vary with cloud cover over a period of minutes or hours. This intermittent and variable nature of renewables contrasts with fossil and nuclear power plants, which produce electricity continuously and uniformly except during times of maintenance, fuel supply disruptions, operational problems, or natural disasters. The intermittency and variability of renewable energy might be partially overcome through the development of advanced storage technologies that provide storage of various quantities of electrical energy for use during renewable energy down time. A wide range of batteries, compressed-air storage, hydrogen generation and fuel cells, and other means of storing and recovering intermittent energy are being studied. Such storage is currently costly, and the combination of renewable electricity generation and reliable storage—or backup reserve capacity from natural gas or other dispatchable sources—will need to be considered by the electrical delivery system in order to maximize the potential contributions of renewable technologies.[98]

Renewable Energy Footprint and Land-Use

Although the amount of renewable energy available from the sun, wind, and water may seem unlimited, the land available for energy development is potentially limited by a number of factors. As mentioned above, these sources are dispersed, and technologies are required to convert the natural form of energy into electricity. For this reason, certain renewable energy technologies available today require large areas of land—a large footprint—for each unit of energy produced.

Figure 14 displays different estimates of the land-use intensities of several energy production technologies. Estimates of the land-use intensity for renewable and nonrenewable sources of energy vary significantly, depending on a number of assumptions. To date, there is no standard methodology to produce these estimates. For example, the extent to which an energy site exclusively "uses" an amount of land is debatable. Only a small portion of area within a wind energy site is actually occupied by the turbines, so remaining land could potentially be—and often is—dedicated to other uses. In contrast, fields of energy crops to be burned in the

---

96 "Eastern Wind Integration and Transmission Study," National Renewable Energy Laboratory, prepared by EnerNex Corporation, February 2011, available at http://www.nrel.gov/wind/systemsintegration/pdfs/2010/ewits_final_report.pdf.

97 "Western Wind and Solar Integration Study," National Renewable Energy Laboratory, prepared by GE Energy, May 2010, available at http://www.nrel.gov/wind/systemsintegration/pdfs/2010/wwsis_final_report.pdf.

98 U.S. Department of Energy, Energy Storage Program Planning Document, http://www.oe.energy.gov/DocumentsandMedia/OE_Energy_Storage_Program_Plan_Feburary_2011v3.pdf.

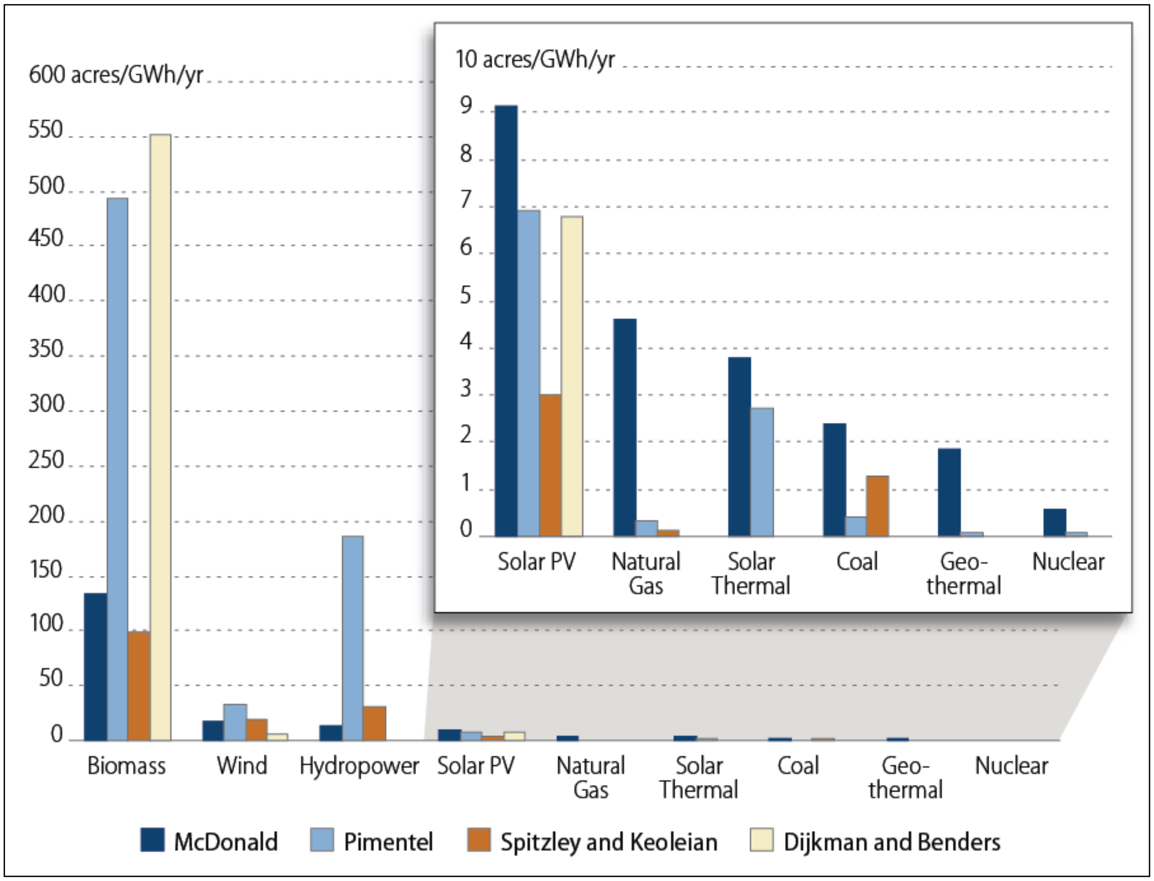
production of electricity will fully occupy their allotted area. Further, energy production for renewables varies substantially with geography. A solar photovoltaic plant of a certain capacity will require less land if located in a region with more intense sunlight. In addition, it is difficult to compare land-use intensities for renewable energy technologies with those of fossil fuel technologies. For example, for fossil fuels, calculations of land-use intensity may include the power plant footprint, plus mining or production area, plus areas occupied by transportation and logistics infrastructure. Thus, the footprint for natural gas may include the gas power plant, but also the areas occupied by gas wells, the roads that connect the gas wells, and the pipelines that transport the gas to market. Also, the areal extent of infrastructure may not fully represent the impact on the landscape. The degree to which such infrastructure divides or dissects ecosystems may also be an important consideration. [99]

The electric energy production technologies with the greatest land-use intensity (amount of land per unit of electrical energy produced) are biomass, wind, hydropower, and solar photovoltaic. Land-use intensities of natural gas, coal, geothermal, and nuclear power are likely significantly smaller than those of other forms of energy production. As demand grows for utility-scale installations of renewable energy, pressure will grow to integrate energy policy with land-use policy.[100] The integration of distributed generation technologies, such as rooftop solar, into existing building structures will help mitigate land-use issues, but there will likely remain a strong need for utility-scale renewable energy installations.

[99] Uma Outka, *The Renewable Energy Footprint*, Stanford Environmental Law Journal, Vol. 30, p. 241, 2011.

[100] Ibid.

Figure 14. Land-Use Intensity for Various Forms of Energy Production



Source: CRS analysis of the following reports:
- McDonald RI, Fargione J, Kiesecker J, Miller WM, Powell J(2009) Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for the United States of America. PLoS ONE 4(8): e6802. doi:10.1371/journal.pone.0006802, Figure 3.
- David Pimentel et al., "Renewable Energy: Current and Potential Issues," BioScience, vol. 52, no. 12 (December 2002), pp. 1111-1120.
- David V. Spitzley and Gregory A. Keoleian, Life Cycle Environmental and Economic Assessment of Willow Biomass Electricity: A Comparison with Other Renewable and Non-Renewable Sources, Center for Sustainable Systems, Report No. CSS04-05R, Ann Arbor, MI, March 25, 2004 (revised February 10, 2005).
- T.J. Dijkman and R.M.J. Benders, "Comparison of renewable fuels based on their land use using energy densities," Renewable and Sustainable Energy Reviews, vol. 14 (2010), pp. 3148-3155.

Notes: GWh = gigawatthours, yr = year; Acres per gigawatthour per year (GWh/yr) is the metric used to compare results from the respective reports. GWh/yr indicates the amount of land required to generate a certain amount of electricity, in this case a gigawatthour. Some studies report land use per unit of capacity, which might be reported as acres per gigawatt (GW). Land use per capacity is somewhat misleading because each energy technology has a different capacity factor, meaning that operational hours for each technology will vary over the course of a year. Reflecting land use as a function of electricity generation takes into account capacity factor differences.

Transmission Availability and Access

Though renewable energy technologies may be used across most of the nation, optimized use of renewable energy must accommodate certain geographic controls. The wind energy resource is richest in coastal areas and the Midwest. Solar energy is optimal in the relatively cloudless southwestern United States. Hydroelectric power has historically been best deployed on large rivers with steep gradients. These geographic concentrations of renewable energy sources often mean that the energy may be optimally produced far from the existing energy demand centers, which are the large cities of the east and west coasts, upper Midwest, and South. Thus, large-scale deployment of renewable energy technologies will likely be accompanied by the need for new electricity transmission infrastructure from the new regions of energy supply to the demand centers.[101] For example, the NREL Eastern Interconnection Report concluded that 20% to 30% wind generation is feasible, but would require "significant expansion of the transmission infrastructure."[102] Not only must a new installation of renewable energy technology be connected to the grid, but the new transmission infrastructure must be sized to the maximum rate of electricity flow even though it may flow intermittently at that rate.

Materials and Resources

While renewable energy sources may provide a virtually infinite supply of energy, building and installing the equipment necessary to convert renewable energy into usable electricity may require significant quantities of materials and other natural resources. For example, wind turbine manufacturing requires a number of materials and resources, the most critical being steel, fiberglass, resins, blade core materials, permanent magnets, and copper.[103] Current solar photovoltaic technologies require materials such as silicon, cadmium, tellurium, silver, and others.[104] Large-scale wind and solar deployment would raise demand for these materials, which in turn may impact their respective prices. This potential price impact may be an important consideration, since the cost of renewable electricity generation is highly correlated with the cost of the energy conversion system (i.e., wind turbines, solar panels, etc.).

Environmental Impact and Aesthetic Concerns

Capturing and converting any energy source—including renewable energy—will have some degree of impact on the environment. Land use and habitat disturbance are potential environmental issues for wind and solar electricity projects. Installation of wind turbines has already attracted attention because of bird mortality, noise, and resulting NIMBY[105] attitudes. Some CSP technologies may require vast amounts of water, although dry-cooling CSP technologies, with lower efficiencies, are available.[106] Water use, land subsidence, and seismicity may need to be addressed by geothermal power plants. Hydropower and ocean-hydrokinetic electricity generation systems may result in water quality degradation, ecosystem disruption, and

---

[101] On July 21, 2011, the Federal Energy Regulatory Commission (FERC) issued Order No. 1000—Final Rule on Transmission Planning and Cost Allocation by Transmission Owning and Operating Public Utilities. This FERC order may result in transmission capacity access for renewables, since transmission planning must take into account federal and state public policy requirements (i.e., renewable portfolio standards, etc.).

[102] "Eastern Wind Integration and Transmission Study," National Renewable Energy Laboratory, February 2011, available at http://www.nrel.gov/wind/systemsintegration/pdfs/2010/ewits_final_report.pdf.

[103] "20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply," U.S. Department of Energy, Energy Efficiency and Renewable Energy, July 2008, available at http://www.nrel.gov/docs/fy08osti/41869.pdf.

[104] National Academy of Sciences, National Research Council, *Electricity from Renewable Resources: Status, Prospects, and Impediments*, National Academies Press, 2010.

[105] NIMBY = Not In My Back Yard.

[106] For more information about potential water issues associated with CSP electricity generation, see CRS Report R40631, *Water Issues of Concentrating Solar Power (CSP) Electricity in the U.S. Southwest*, by Nicole T. Carter and Richard J. Campbell.

animal mortality. Biomass projects impact the environment through emissions such as nitrogen oxides (NO_x), carbon dioxide (CO_2), and others, as well as land use changes associated with producing biomass feedstock.[107] These, and other, potential environmental impacts may need to be considered as policy makers look to balance the desire to increase electricity production from renewable sources of energy with environmental objectives.

Infrastructure Requirements

All forms of energy production and delivery require some form of infrastructure. Coal is delivered by an extensive network of railroads, and natural gas is delivered via a large network of pipelines. In addition to new transmission requirements, some renewable energy sources may require investments in specialized infrastructure in order to provide a source of renewable electricity. One example is offshore wind energy. Specialized vessels, purpose-built portside infrastructure, undersea electricity transmission lines, and grid interconnections will likely be required to support offshore wind development. According to DOE, "these vessels and this infrastructure do not currently exist in the U.S."[108] Such specialized infrastructure requirements may also be a consideration for policy decisions associated with certain other types of renewable energy.

Technology Development and Commercialization

Some renewable electricity generation technologies are not yet commercially available. Private and public investments are being made in renewable electricity generation technologies, to include venture capital firms, private and public corporations, and the U.S. DOE through its Advanced Research Projects Agency—Energy (ARPA-E) program office. While ARPA-E and DOE's Office of Energy Efficiency and Renewable Energy provide funds to support technology R&D, concept demonstrations, and technology performance optimization, bridging the gap between these activities and commercialization may require significant amounts of funding. Commonly known as the commercialization "valley of death," several additional market development activities that might include technology performance characterization and validation, operational reliability assessments, accurate quantification of maintenance and operations costs, etc., may be necessary in order for new technologies to qualify for private equity and bank/debt finance in support of commercial projects. Obtaining the funds necessary to commercialize new technologies can be difficult and costly.[109]

Policy and Regulatory Challenges

Certain federal and state-level policies have served to stimulate growth of renewable electricity generation. Federal policies such as production and investment tax credits for certain renewable energy property, along with other tax-favored finance options, have created financial incentives for building and operating renewable electricity generation projects.[110] Other federal financial

---

[107] "Electricity from Renewable Source: Status, Prospects, and Impediments," Chapter 5 – Environmental Impacts of Renewable Energy, National Academy of Sciences, 2010.

[108] "A National Offshore Wind Strategy: Creating an Offshore Wind Energy Industry in the United States." U.S. Department of Energy, Energy Efficiency and Renewable Energy, February 2011, available at http://www1.eere.energy.gov/windandhydro/pdfs/national_offshore_wind_strategy.pdf.

[109] For more information on the commercialization "valley-of-death," see "Crossing the Valley of Death: Solutions to the next generation clean energy project financing gap," *Bloomberg New Energy Finance*, June 21, 2010.

[110] For more information on energy tax policy see CRS Report R41769, *Energy Tax Policy: Issues in the 112th*

incentives are also available for renewable energy.[111] Furthermore, the American Recovery and Reinvestment Act (ARRA) provided new policies such as the Section 1603 cash grant option for renewable electricity generation projects and the Section 1705 Loan Guarantee Program that provides government-backed debt financing for certain renewable energy projects.[112] State-level policies, such as renewable portfolio standards, have served to create market demand for renewable electricity.[113] Furthermore, there is some interest in establishing a federal renewable or clean energy standard, which may create additional demand for renewable electricity generation.[114]

Federal policies that support renewable electricity generation typically are available for a defined period of time, at the end of which the policies expire. Some in the renewable electricity industry argue that the sudden expiration of certain federal policies has resulted in market uncertainty and downward pressure on renewable electricity market growth.[115] The historical start-stop nature of federal policies may be challenging to the renewable energy industry due to a lack of long-term financial certainty for renewable electricity generation projects. On the other hand, some policy makers may not wish to create a policy environment that results in a renewable energy industry that is dependent on federal financial incentives. Balancing policy objectives that might stimulate a solid base for renewable electricity, while at the same time eliminating a dependency on federal subsidies, may be a consideration for policy makers.

Related Issues

Energy Efficiency and Curtailment

Although this report does not provide a detailed analysis of energy efficiency and conservation, it is widely acknowledged that both energy efficiency (doing as much or more with less energy and eliminating waste) and curtailment of demand (doing less with less energy) provide enormous opportunities for reducing or controlling the energy resources of the nation. By addressing the demand side of the energy equation, as well as the supply side, the United States can extend the energy resources that it consumes. Efficiency and demand curtailment will not, by themselves, meet the demand for energy in the future, but these strategies will likely reduce the amount of new energy needed.[116]

Congress, by Molly F. Sherlock and Margot L. Crandall-Hollick.

For more information on tax favored finance options see CRS Report R41573, *Tax-Favored Financing for Renewable Energy Resources and Energy Efficiency*, by Molly F. Sherlock and Steven Maguire.

111 For more information see CRS Report R40913, *Renewable Energy and Energy Efficiency Incentives: A Summary of Federal Programs*, by Lynn J. Cunningham and Beth A. Roberts.

112 For more information regarding Section 1603 of ARRA see CRS Report R41635, *ARRA Section 1603 Grants in Lieu of Tax Credits for Renewable Energy: Overview, Analysis, and Policy Options*, by Phillip Brown and Molly F. Sherlock.

113 For more information on state incentives for renewable energy, see the Database of State Incentives for Renewables and Efficiency at http://www.dsireusa.org/.

114 For more information see CRS Report R41720, *Clean Energy Standard: Design Elements, State Baseline Compliance and Policy Considerations*, by Phillip Brown.

115 One example of this scenario might be the expiration of production tax credits in 2000, 2002, and 2004. For more information, see http://www.awea.org/issues/federal_policy/upload/PTC_April-2011.pdf.

116 One concept worth noting here is known as the Jevons Paradox, which indicates that as efficiency increases the amount of resources demanded will also increase, not decrease as might be expected. William Jevons, in 1865, observed that as technology improved the efficiency of coal use, consumption of coal actually increased across several

The benefits of more efficient use of energy are being sought by a wide range of citizens, homeowners, manufacturers, and governments. Lower costs, reduced greenhouse gas emissions, and reduced need for expansion of supply are key motivators to increase energy efficiency and conservation. Energy efficiency can be measured for individual devices such as appliances, automobiles, and light bulbs, but derivative indicators are used to measure levels and trends in energy efficiency at a national level. The most common national indicator of energy efficiency and curtailment is energy intensity.[117] Energy intensity is measured in units of energy per dollar of Gross Domestic Product (GDP). As **Figure 14** shows, the energy intensity of the United States has been dropping steadily for decades, despite the steady growth in total energy consumption. There are many reasons for this trend, of course, including a gradual change from a manufacturing economy to a more service-oriented economy, but ongoing efforts to promote energy efficiency and conservation are clearly succeeding in the United States. For example, one study estimates that improving the energy efficiency of buildings in the United States could save $170 billion per year in energy costs through 2030.[118] Numerous other opportunities exist for improving efficiency or curtailment in energy use in the United States.[119]

---

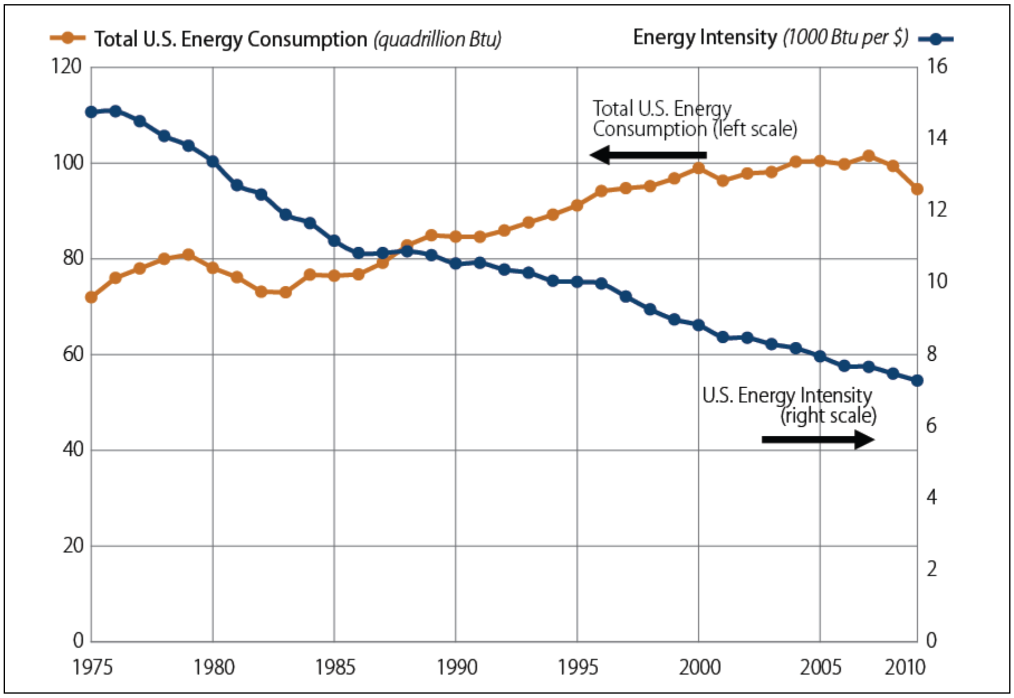
industries. Whether or not the Jevons Paradox is applicable today is debatable, with experts presenting arguments that support and refute the Jevons Paradox. A high level overview of the Jevons Paradox is available at http://en.wikipedia.org/wiki/Jevons_paradox. For more information, see CRS Report RL31188, *Energy Efficiency and the Rebound Effect*, by Frank Gottron.

[117] Energy Information Administration, http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=92&pid=46&aid=2.

[118] Rich Brown, Sam Borgeson, Jon Koomey, Peter Biermayer, "U.S. Building-Sector Energy Efficiency Potential", Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, Report LBNL-1096E, September 2008.

[119] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, http://www.energy.gov/energyefficiency/index.htm, and the U.S. Environmental Protection Agency, http://www.energystar.gov/.

Figure 15. Total U.S. Energy Consumption and Energy Intensity, 1975-2009



Source: Energy Information Administration, http://www.eia.gov/emeu/aer/pdf/pages/sec1_13.pdf.

Note: Energy intensity is the total primary energy consumption per real dollar of Gross Domestic Product.

Biofuels

Biofuels are liquid fuels produced from plant materials, which makes them a renewable commodity. The major biofuels are fuel ethanol and biodiesel, though other kinds of alcohols and hydrocarbons can also be synthesized from biological materials. Both fuel ethanol and biodiesel are currently used primarily as blending agents with conventional gasoline and diesel fuel, though both can conceivably be used in their pure form with some modifications to engine fuel systems.[120] Unlike the other kinds of biomass discussed above, liquid biofuels are normally used as transportation fuels and are not used to generate electricity. Liquid biofuels are important because certain forms of transportation such as aircraft and heavy trucks cannot easily be converted to electricity or other propulsion technologies. In 2009, the United States consumed 99 million gallons of fuel ethanol as an 85% blend (E85), 10.7 billion gallons of fuel ethanol as a 15% blend (E15) in gasoline, and 316 million gallons of biodiesel.[121]

For additional information on biofuels see the following CRS reports.

- CRS Report R41282, *Agriculture-Based Biofuels: Overview and Emerging Issues*, by Randy Schnepf.
- CRS Report RL34738, *Cellulosic Biofuels: Analysis of Policy Issues for Congress*, by Kelsi Bracmort et al.

[120] National Renewable Energy Laboratory, http://www.nrel.gov/learning/re_biofuels.html.

[121] Energy Information Administration, http://www.eia.gov/renewable/alternative_transport_vehicles/pdf/afv-atf2009.pdf

- CRS Report R41106, *Meeting the Renewable Fuel Standard (RFS) Mandate for Cellulosic Biofuels: Questions and Answers*, by Kelsi Bracmort.
- CRS Report R40110, *Biofuels Incentives: A Summary of Federal Programs*, by Brent D. Yacobucci.
- CRS Report R40155, *Renewable Fuel Standard (RFS): Overview and Issues*, by Randy Schnepf and Brent D. Yacobucci.

Additional Considerations for Renewable Electricity in the United States

The Scale of U.S. Energy Consumption

One important aspect of the expansion of renewable forms of energy, often overlooked or under-appreciated, is the scale or magnitude of energy use in the United States. It is not only *what kind* of energy is used, but *how much* energy the United States uses on a daily, monthly, and annual basis. By any measure, the amounts of energy used by the United States are prodigious, and replacing a significant proportion of fossil fuels with renewable forms of energy would be a formidable task. Alternatives to fossil fuels must be produced on a very large scale and must be available to all parts of the nation to provide the enormous and increasing amounts of energy demanded by the U.S. economy. Whether individual renewable energy installations are large (utility-scale) or small (distributed), the total combined output must accommodate the very large—and increasing—demand for energy. Current electricity generation is dominated by coal, natural gas, and nuclear (see **Table 6**). Only 8% of total energy use in the United States is renewable, and 53% of that is for electricity generation. In 2009, total U.S. energy use was 94.6 quadrillion Btu, and renewable electricity accounted for about 4 quadrillion Btu.[122] Therefore, any serious proposal to displace fossil fuels with renewable energy must include massive growth in renewable energy technology deployment.

Table 6. Total U.S. Electricity Generation, By Source, 2009

Generation fuel	GWh	%
Coal	1,755,904	44.45
Petroleum	38,937	0.99
Natural Gas	920,979	23.31
Other Gases	10,632	0.27
Nuclear	798,855	20.22
Hydroelectric Conventional	273,445	6.92
Wind	73,886	1.87
Solar Thermal and Photovoltaic	891	0.02
Wood and Wood Derived Fuels	36,050	0.91
Geothermal	15,009	0.38
Other Biomass	18,443	0.47

[122] U.S. energy use at the national scale is measured in quadrillion British thermal units (Btu), or "quads."

Generation fuel	GWh	%
Pumped Storage	-4,627	-0.12
Other	11,928	0.30
All Energy Sources	**3,950,332**	**100.00**

Source: EIA, http://www.eia.doe.gov/cneaf/electricity/epa/epaxlfilees1.pdf.

Notes: Electricity generation from pumped storage is negative since pumping water into a storage reservoir requires more electricity than that generated when the stored water is used to operate a turbine. Pumped storage projects are typically based on opportunities to pump water into a reservoir when electricity prices are low (typically at night), then use the stored water to generate electricity when prices are high (typically during peak demand hours).

Relationship Between Renewable Electricity and Imported Energy

Petroleum consumption may be displaced by the production of biofuels, but most renewable energy technologies are designed to generate electricity. Therefore, the use of renewable energy to generate electricity in today's U.S. market would displace only those fossil fuels that are used to generate electricity, and the United States uses almost no imported fossil fuels to generate electricity. For example, the U.S. transportation system is 94% reliant on petroleum (**Figure 1**), and the use of renewable electricity for transportation might require increased electrification of the transportation system. Consequently, the only way that increasing production of renewable electricity would affect oil imports is if the U.S. transportation system is electrified so that domestically generated electricity substitutes for oil. Likewise, any process in which the burning of natural gas is used for direct heating would need to be electrified in order for renewable energy to substitute. More than 93% of U.S. coal consumption is used to generate electricity, so adopting renewable energy sources to generate electricity could potentially reduce demand for coal, but would have no effect on energy imports because virtually all of U.S. coal is produced domestically.

International Renewable Electricity Markets

Recent news reports emphasize how successful China and other nations have become in developing and deploying renewable energy technologies. Indeed, China is constructing impressive amounts of renewable energy installations, but the United States remains one of the world leaders in renewable energy capacity and deployment. For example, **Table 7** shows that the United States leads the world in installed non-hydropower renewable electricity generation capacity, biomass power, and geothermal power. While the United States ranked second, behind China, in total wind power capacity, the United States ranked first in 2010 in terms of *operational* wind power capacity.[123] In 2009, the United States generated more electricity from non-hydro renewable energy sources than any other country in the world. However, when hydropower is included, China led the world in terms of total renewable electricity generation (see **Figure 16**).

[123] REN21. 2011. Renewables 2011 Global Status Report (Paris: REN21 Secretariat), http://www.ren21.net/REN21Activities/Publications/GlobalStatusReport/GSR2011/tabid/56142/Default.aspx.

Table 7. Existing Renewable Energy Capacities at the End of 2010

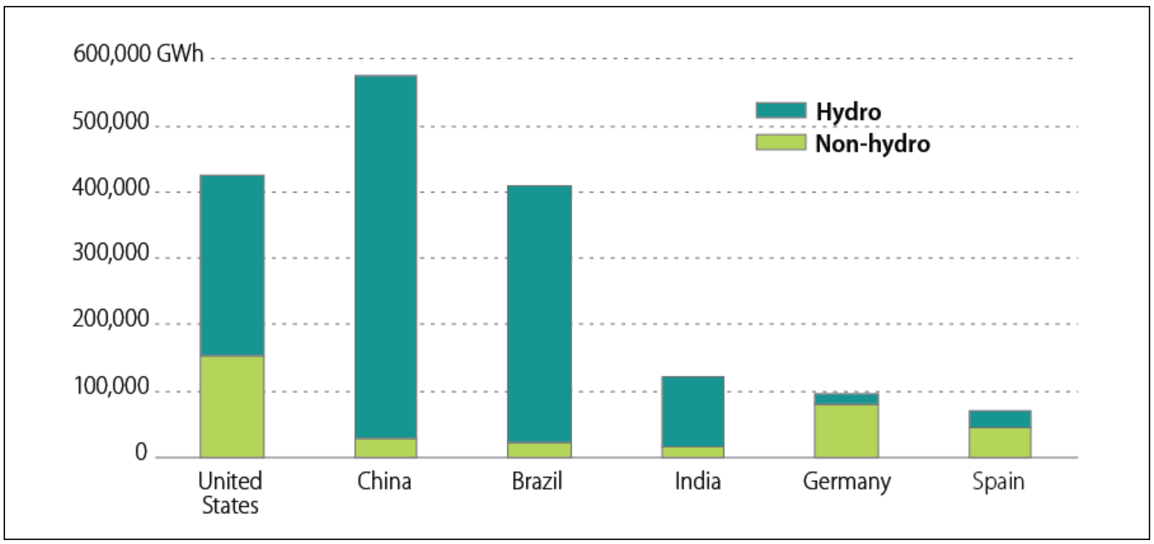
(Country ranking for selected categories)

Rank	Renewables power capacity (not including hydro)	Renewables power capacity (including hydro)	Wind power	Biomass power	Geothermal power	Solar PV	Solar hot water/heat
1	United States	China	China	United States	United States	Germany	China
2	China	United States	United States	Brazil	Philippines	Spain	Turkey
3	Germany	Canada	Germany	Germany	Indonesia	Japan	Germany
4	Spain	Brazil	Spain	China	Mexico	Italy	Japan
5	India	Germany/ India	India	Sweden	Italy	United States	Greece

Source: REN21. 2011. *Renewables 2011 Global Status Report* (Paris: REN21 Secretariat), available at http://www.ren21.net/REN21Activities/Publications/GlobalStatusReport/GSR2011/tabid/56142/Default.aspx.

Figure 16. Total Net Renewable Electricity Generation, 2009

(Selected Countries)



Source: Energy Information Administration, International Energy Statistics, http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=6&pid=29&aid=12.

Notes: Non-hydro includes generation from wind, solar, geothermal, tide and wave, and biomass and waste.

Future Trends in Renewable Electricity

The potential for renewable electricity generation in the United States is very large, yet current use of renewable energy for electricity production is relatively modest, constituting only 11% of total electricity generation and 8% of total energy consumption. Based on the current status of renewables in the United States, policy makers may consider some key questions about the future of renewable energy:

- Should the United States actively seek greater use of renewable energy to supply electricity, or should the energy and electricity markets be allowed to work without further interference with the existing structure of subsidies and incentives?

- If greater use of renewable energy for electricity is desired, what are the key barriers or actions that should be addressed by federal policy?

Future trends in renewable electricity will depend heavily on the cost of both renewable technologies and fossil fuel costs, and on government incentives for renewable energy. In the absence of subsidies for renewable electricity technologies, and in the absence of accounting for external costs of using fossil fuel combustion to generate electricity, several renewable electricity technologies are currently not commercially viable, or only marginally so. Reference case projections by EIA of growth in wind and solar electricity to 2035 are predicated on the use of renewable portfolio standards, renewable fuel standards, and subsidies in the tax code.[124] With low coal and natural gas prices, and high renewable energy technology costs, and the absence of regulation or subsidies, renewable electricity may not increase significantly. Without some form of carbon pricing or other consideration of the externalities of fossil fuel combustion, the United States may remain in an era of relatively low-cost fossil fuel electricity for decades.

However, policy makers may decide that growth in renewable electricity is desirable because of concerns about greenhouse gas emissions and climate change, because fossil fuel supplies are ultimately finite, and because of a desire to position the United States as a global leader for renewable energy technology and manufacturing. Renewables could be made more cost competitive by means of improved renewable technologies or revised cost of carbon-based fuels, but financial or regulatory incentives may be required to make certain renewable sources more economically viable in the short term.

In the event that levelized costs of renewable electricity become competitive with those of fossil fuel electricity, the additional issues of intermittency/variability, land-use and footprint, the need for additional transmission, plus other resource and environmental impacts of renewable electricity will need to be addressed by local, state, and federal officials and policy makers.

Conclusion

Cumulative U.S. renewable electricity generation capacity more than doubled from 2006 to 2010, increasing from approximately 22 GW to nearly 55 GW.[125] In 2010, renewable sources of energy provided approximately 11% (7% from hydropower and 4% from other renewables) of total net electricity generation and the EIA AEO 2011 reference case projects that renewable electricity generation will increase to between 14% and 15% by 2035.[126] The renewable electricity generation research conducted for this report indicates that the potential may exist for renewable energy sources to make a sizeable contribution toward total U.S. electricity generation demand. However, renewable electricity generation will likely encounter serious challenges, issues, and barriers as technologies and projects look to realize large-scale deployment. As Congress evaluates various energy policy objectives, policy makers may move to holistically evaluate the potential intended benefits, such as emissions reduction and job creation, with potential risks and

[124] Energy Information Administration, Annual Energy Outlook 2011, http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf.

[125] Eckhart, M. "Renewable Energy Exceeds 50 GW and Enters Decade of Scale-Up," Infrastructure Solutions Magazine, April 2011, available at http://www.acore.org/wp-content/uploads/2011/04/Infrastructure-Magazine-Article-V4.pdf.

[126] Energy Information Administration, "Annual Energy Outlook 2011: with projections to 2035," DOE/EIA-0383(2011), April 2011, available at http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf.

consequences, such as electricity cost/price increases and electricity delivery reliability issues associated with increasing renewable electricity generation.

Author Information

Phillip Brown
Analyst in Energy Policy

Gene Whitney
Section Research Manager

Acknowledgments

The authors would like to recognize the valuable contributions from Steven Deitz and Amber Wilhelm during the preparation of this report.

Disclaimer